Electronics, Computers and Telephone Switching

A book of technological history as Volume 2: 1960 -1985 of "100 Years of Telephone Switching"

North-Holland Studies in Telecommunication
Volume 13

Robert J. Chapuis
Amos E. Joel, Jr.

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STUDIES IN TELECOMMUNICATION

VOLUME 13

NORTH-HOLLAND PUBLISHING COMPANY – AMSTERDAM · NEW YORK · OXFORD

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ELSEVIER SCIENCE PUBLISHERS B.V.
Sara Burgerhartstraat 25
P.O. Box 211, 1000 AE Amsterdam, The Netherlands

Distributors for the United States and Canada:

ELSEVIER SCIENCE PUBLISHING COMPANY, INC.
655 Avenue of the Americas
New York, N.Y. 10010
U.S.A.

ISBN: 0 444 88042 9

Printed in The Netherlands

Dedicated to the patience
of our wives,
Hélène and Rhoda,
from Robert and Amos, respectively

PREFACE

Volume I (1878–1978) of "100 Years of Telephone Switching" by Robert Chapuis has been published in 1982. It was an excellent review of the history of switching, covering from the manual service to the automatic switching of the electromechanical technology.

What R. Chapuis and his co-writer, Amos Joel, are now describing in this Volume II is the birth and deployment of switching in modern telephony.

R. Chapuis was engaged in the work of CCITT from 1949 to 1985 and was able to follow step by step the development of switching technology in all countries of the industrial world. Amos Joel is rightly considered as the father of modern switching. The principle of stored program control (SPC) put on the market by Bell Laboratories in the 1960s came to be the fundamental concept in modern switching technology, a development in which Amos Joel took a large part. You could hardly pick any author more apt to speak about "Electronics, Computers and Telephone Switching" than Robert Chapuis and Amos Joel.

Telecommunications is now the most expansive business area and there is no sign of slowdown. The main reason is of course the tremendous technical development making it possible to offer new and better telecommunication services at lower rates, relatively speaking. Expressed in dollars, they have actually gone down in international traffic. On US-European relations, the rates are now only 25% of what they were 30 years ago.

Let me mention some historical mileposts of this fantastic development:

The transistor	1947
The integrated circuit	1958
Telstar	1962
The Stored Program Control and the ESSs	1965
Conception of step index optical fibre	1966
The microprocessor	1971
Fiber optical transmission in operation	1976

The 1970s and 1980s were marked by a rapid development of telecommunication networks. New network structures have evolved, based on CCITT/ITU standards in digital transmission and signalling. The digital basic network supported by CCITT signalling system No. 7 is now supplemented by access networks for ISDN (both voice, text and data) and mobile communication. Right now, mobile communication excels all other ways and means of communication and, on the other side of the year 2000, we may all have a personal telephone number that we may use anywhere in the world! Before that, we will have data networks, both public and private, accessing to the basic digital network.

Another feature of the digital networks will be special databases providing new special services. With today's rapid switching, every single switching point need not be equipped for all network services; instead, network services may be concentrated to certain databases in the network. The telecommunications network will gradually become a service-integrated network. With a wide choice of terminals, applications and support systems, the customer will soon be able to select the

combination he prefers of the facilities offered by the network.

Broadband services at rates exceeding 100 Mbit/s will also be available in the telecommunication networks of the 1990s, which will also contribute to an increasing number of services and a steady growth of traffic.

The authors have written the fantastic story of switching leading the 1970s and 1980s telecommunications up to their extraordinary developments of the 1990s. Their book is extremely interesting and instructive and I recommend it to anyone wanting to know more about the emergence of modern telecommunications and their evolution.

Stockholm, April 1990 Torsten LARSSON

Torsten Larsson, so well known in the international telecommunication community, has been Technical Director since 1963 and Deputy Director General of Swedish Telecom ("Televerket") before retiring by the end of 1989.

FOREWORD

1. In what spirit was this book written?

To give a clearer picture of the spirit in which this book was written, let us resort – as we do often but hopefully not too frequently throughout this work – to the convenient services of the metaphor. This we shall do by reference to two evocative images, one taken from professional life and the other more domestic.

1.1. Once again, the telecommunication engineer has gone off on mission to a far-off country, to attend one of those innumerable meetings which are part of his duties. In the plane which carries him home, he flies over unknown lands and is quite unaware of the route followed by his flight. To get his bearings and to pass the time, he tries to make out the landscape which unfolds itself, in the bright light of day, beneath the aircraft flying at a high altitude.

There are some arid mountains and stretches of desert with only a thin straight line which must be a track, or perhaps a road. And now, among the hills, a river begins to meander; on its banks, in the valley, chessboards of cultivated fields cluster around straggling villages ... Then, with converging roads and railways, come towns, large and small, but which being unidentified, remain completely anonymous for the viewer. And then a seashore, but one which he cannot place ...

Then a very large city suddenly appears. Its shape, its bridges and its harbour provide the necessary reference points.

All at once, our observer realizes where he is. In his mind's eye, the landscape he has flown over is superimposed on a very clear picture of a geographical map, with the exact names of towns and geographical features, and even with those lovely ideal lines, invisible on the ground, which are the frontiers of the countries he has crossed.

1.2. For the devotee of jigsaw puzzles, who collects the scattered pieces together, patiently classifies them by colour and shape and then fits them together ... so many painstaking processes have to be performed before the whole picture finally emerges to his satisfaction.

1.3. It is exactly the same for an engineer who is really interested in his subject.

If he wants to venture beyond the narrow field of his daily professional activities, if he wants to cast a retrospective glance over that which has led to the present stage of development of his profession, how many details must be considered! How many inventions, innovations, theories and transfers of acquired knowledge from one technology to another had to take place before the body of knowledge he himself possesses could be built up. And how much of this knowledge, patiently acquired but forgotten or relegated to the background of his memory and without any apparent direct bearing on his profession, may nevertheless, in the final count, have a decisive effect on the advances made in its development.

1.4. To recapitulate, juxtapose and demonstrate the interrelationships between *a priori* rather different techniques and to try thus to give a coher-

ent picture of what, over the past 30 years, has constituted a technological revolution – those are the basic objectives of this book and the subjects of this Volume II.

2. Reading the book. Its structure

2.1. This is the second and concluding volume on the present history (until 1990) of telephone switching. From an historical viewpoint it is an in-depth examination of the factors that have influenced and the results that have been achieved in the development of *electronic* central office *telephone switching systems*.

The book explores both the technology and marketing decision-making in a world-wide industry where product purchases represent long-term decisions and where the rate of change of the technology has been incredibly rapid. The context in which switching systems were developed and deployed is sometimes as important as system descriptions. The reader should consider the contents of this book as a whole and not just as a reference to a specific system of interest.

The book deals essentially with the mainstream switching systems required for the public network. It does not cover the history of switching for private switching installations (PBX, etc.) or cellular mobile radio services, nor does it refer to data switching, especially packet switching, etc., which are in a different class of products.

The book is about the history of core switching systems and signaling that have been developed to form public telecommunication networks. Claims to being first in specific niches are made by many, particularly in the highly competitive arena switching currently finds itself. Furthermore readers with subsidiary interests, such as networks, maintenance, operations and administration systems and equipment will probably be stimulated to consider the history of those related subjects which are also not covered.

While we could have included many more figures, photographs and tables, we have selected from many that would have equally qualified. Unfortunately there is a limit to the number of these items that can be included economically.

2.2. Continuation, as Volume II, of a first book (Volume I – Manual and Electromechanical Switching: 1878–1960s") [1], the book's structure is on the same lines as Volume I. It includes a division into:

- Parts (Roman numerals)
- Chapters (Arabic numerals
- Sections (Arabic numerals)
- with an index numbering of sections and sub-sections [2].

2.3. Boxes (lettered) have been introduced to serve two very different purposes:

a) for the layperson who is not an engineer, to explain things which are quite obvious to engineers,
b) for engineers who want to have more technical details than are given in the main text, to enable them to find them.

Bibliographical references are indicated in square brackets and listed at the end of each Chapter.

2.4. For the benefit of switching engineers who might probably be more interested in switching systems than in the history of technology, let us reiterate here what is said in section 5.2 of Chapter I-2: they can skip Parts III and IV and resume their reading at Part V.

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[1] Published in 1982 under the title "100 Years of Telephone Switching" by North-Holland, Amsterdam and New York.

[2] Systematic numbering has the drawback of lending the book an appearance somewhat dogmatic in style, one which in no way corresponds to its purely historical spirit or reflects the authors' intentions. Its use is only a highly convenient device for feeling one's way through a maze of interlocking stories which are, after all, fairly complicated. Critics of the practice are invited kindly to excuse it as a fad on the part of persons in whom this method of drafting has been ingrained by long years of professional activities involving the publication of many technical works.

3. How the book took shape

Writing this book has been a lengthy business.

3.1. In 1983, a shared interest in evoking the memory of all they had created or seen created during almost 40 years of professionnal life enabled the author of Volume I to call upon the renown competence of Amos E. Joel to join in the penning of Volume II on electronic switching. This marked the beginning of a seemingly interminable effort of collaboration between them, one stretching over seven whole years and involving:

- a stream of transatlantic correspondence between the two authors;
- a few reciprocal visits to New Jersey and France to take stock of progress in drafting or make appropriate changes;
- exacting self-secretarial work on each side, both authors being in retirement and therefore deprived of the excellent logistics to which they were accustomed when still in harness; for one this included a slow apprenticeship in handling a PC and typing onto diskette;
- and, from then on, once a cruising speed had been reached, a further spate of exchanges, this time of diskettes which still had to be corrected many times before delivery to the publisher.

As time passed, further events occurred and more new developments emerged, thus raising new subjects to be included if only succinctly. Fortunately, the International Switching Symposium (ISS) of Stockholm in May 1990 provided a convenient target which succeeded in encouraging both the North-Holland publishing house and the authors through the last lap of a long race.

3.2. Once the plan of the book had taken shape following a few retouches, the initial drafting of the different chapters quite naturally took on a quasi-geographical distribution. However, the drafting of the whole must be regarded as a joint effort between the authors, not as a collection of Chapters written individually by one or the other.

This distribution of the initial drafting may give rise to criticisms on the grounds that some Chapters and the way in which certain subjects are developed betray a hint of idiosyncracy on the part of the authors, based on subjects they each knew only too well: American achievements on one side, international CCITT matters on the other. Such a situation would simply mirror an innate and perfectly natural reflex on the part of each author, one which the reader will hopefully find pardonable.

4. Acknowledgments

4.1. Many friends and former colleagues both at the office and at international meetings have helped in the preparation of this book:

- by their encouragement when the perhaps excessively long drafting process seemed endless;
- by their contribution of invaluable documents on subjects all too quickly forgotten in the concerns of the past ten years;
- and lastly, by the critical yet competent attention which some of them paid to the drafting of this or that Chapter.

The list of these friends and colleagues is a long one:

- in Austria: Hans Zemanek (for Part III of the book)
- in Belgium and Saoudi Arabia: Robert Vinckier
- in France: Jacques Arbeit, Bernard Canceill, André Jouty (†), Louis-Joseph Libois, Jean-Jacques Muller
- in Germany (FRG): Rudolf Hannig, Karl Heinz Rosenbrock
- in Italy: Furio Vallese
- in Japan: Kohei Habara, Motoo Hoshi, Hiromasa Ikeda, Toshisada Okabe
- in Sweden: Torsten Larsson, the retired Director-General of Televerket, who did the honour of writing the Preface to this work, L.A. Andersson and John Meurling
- in the United Kingdom: David Thomas
- in the United States: Marcy Goldstein, F.F. Taylor, Jack Ryan, Gerd Wallenstein
- in USSR: Dimitri Joukowski

(Given the gestation period of this book, and now that the time has come to write a foreword, it is conceivable that some people may have been omitted from the above list; if such is the case, it is sincerely hoped that they will excuse the authors.)

4.2. Lastly, in the case of one of the two authors, most of whose texts had to be translated from manuscripts originally drafted in French, the author concerned wishes to extend genuine thanks to Damian Plumley, an ex-colleague and friend at the ITU, who attended to the translation of many Chapters as they emerged from the PC.

4.3. Thanks are also due to the supremely cooperative and obliging authorities and colleagues of often visited libraries, particularly those of Bell Laboratories at Holmdel and the ITU in Geneva.

4.4. At the end of the book the reader will find credits to all the bodies which have dipped into their archives to provide the authors with many of the illustrations and figures which appear among the text.

4.5. The writers invite correspondence with those who have like interests and facts to contribute to the history of switching to add to the considerable collection of information that they hold, much of which could not be included in this work.

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CONTENTS

Indexes

Part I

Introduction to the book

CHAPTER I-1

INTRODUCTION TO THE BOOK

1. This is a technological history book

1.1. Many books have appeared in the past few years on the new switching technology in connection with electronic or digital switching. Most of them are didactic works and, by far and large, excellent. Indeed, they are extremely useful to and highly appreciated by engineers who have to assimilate all the subtleties of a relatively new technique. Those who were trained in the old school of electromechanical switching now have had to relearn its rudiments. The following frequently quoted references might be useful for those unfamiliar with electronic switching:

- Telecommunication Switching Principles, by M.T. Hills, MIT Press, 1979
- An Introduction to Digital Integrated Communications Systems, by H. Inose, University of Tokyo Press, 1979
- Electronic Switching, by "Grinsec", North Holland, English edition: 1983, (French edition:1981)
- Fundamentals of Digital Switching, edited by John C. McDonald, Plenum Press, 1983, (second edition, 1990),

and, of course, many other books in many languages.

1.2. It is not the authors' intention to take up the tenor of those works, nor to explain in detail, the peculiarities of specific systems. The various systems available are, at present, subject to sharp, intensive, commercial competition and to commend any of them would mean a departure from the role of impartial observers of historical processes which the authors have assumed.

There are many subtle differences between switching systems. Besides the installed price of a switch, there are many other factors that must be taken into account in evaluating and choosing one or more switching systems for general application in a particular situation. It is not the intention of this book to provide information of the type necessary for the evaluation of switching systems except what the reader may derive in the context and from the specific experiences and examples that history provides us.

The purpose of this book lies outside the usual framework of studies devoted to technology in a given branch of industry.

1.3. Its primary objective is to show how, in only a quarter century the highly specialized telephone switching industry was completely transformed and has radically revolutionized its manufacturing processes and its products, a phenomenon less clearly known to the public, if not altogether ignored. The change was so drastic that it has sometimes been compared to the metamorphosis of the same insect which progresses from the caterpillar phase to that of the butterfly.

The second purpose of the book is to show how this change has occurred within the context of the major electronic revolution so characteristic of the quarter of the century, following the invention of the transistor and, in its wake, the advent of integrated circuits.

1.4. Admittedly, this electronics-induced development is by no means peculiar to the switching industry. Similar changes have taken place in several fields, including the watch industry to name but one example. With electronics, many new industries have proliferated concurrently and expanded from scratch in even more spectacular way than switching. There are, for example, such new lines of commodities as minicomputers and pocket calculators, now highly popular even among children. Unlike switching, however, the entire range – quartz minicalculators, watches or video recorders – is essentially intended for the man-in-the-street, i.e. for the individual.

1.5. Telephone switching is another matter

In the case of public telephony the customers to whom manufacturers offer their equipment are State Administrations which hold a legal monopoly in a given country, or, until recently, private companies holding a *de facto* monopoly over extensive vast areas. The products of the switching industry have to be incorporated and fitted into networks that have been patiently established and gradually developed over time. The substantial investments needed to set up these networks and the amount of capital required to introduce new techniques without too many changes, account for a considerable amount of inertia.

To produce a properly working switching system is one thing. For a telecommunication-operating agency to select a new system to be introduced into a network and used for many years to come is quite another matter. Prudence, circumspection (and, sometimes, even excessive caution before the adoption of the right decision, often belatedly) – these are virtues which govern and, as we shall see, have always governed decision-making in different countries. Such decisions have always had to take into account many important and often highly subjective factors, depending on a country's industrial environment and political climate.

This decision-making is influenced by a tendency to emulate, to follow suit, so that, in the chronological history of the new switching techniques, abrupt changes in the approach are discernible. What was regarded as a hazardous venture which only few dared undertake, suddenly turns into a respected and quasi-official technique. As in many other fields, an excellent relevant quotation from Alexander Pope may be applied to switching:

> "Be not the first by whom the new is tried,
> Nor yet the last to lay the old aside."

2. Invitation to a worthwhile tour

2.1. An ethnology of switching experts

Telephone switching, a technological field with applications at every dry point on our planet, is considered by those who appreciate its marvels and subtleties as a wonderland worth discovering.

Yet, it is a little known land, a *terra incognita*, despite the many virtues of its population which is:

- industrious and skillful, endowed with outstanding intelligence rarely encountered elsewhere;
- always at the disposal of anyone who needs its good offices;
- of a general robust constitution.

In addition, this population has a sense of sportsmanship and does not flinch from competition; indeed, when called upon by its leaders, it even displays a combative nature to the point that fratricidal strife between rival clans is by no means unknown.

The above is a formidable list of virtues!.. On the other hand, its engineering population has the flaws of being somewhat introvert. Outside their own narrow circle, members of the tribe tend to be uncommunicative, lead a hermetic life, and often resign themselves to a back seat in the business world.

Worst of all, is the problem of the natives' language which is frequently incomprehensible to outsiders.

The authors' aspiration is to attempt to break through this language barrier, shed light on the

population's achievements and describe the monuments it has erected and the tribulations it had to endure over the 35 years between 1954 and 1989 in adapting themselves to a completely new way of life.

The engineer who belongs to or has been a member of the tribe will discern traces of the achievements in which he participated, while *technological historians* will eventually discover ample material for their researches (see Box A).

Last but not least, post-graduates wishing to embark on a telecommunication career may be motivated by these veterans' accounts and follow in the footsteps of the electronic switching pioneers.

2.2. A "travel guide" book

2.2.1. The major edifices in which the modern world takes most pride are of the highly visible variety intended to catch the public eye. These prestige works are focal points of attraction in all travel brochures and include such marvels as: skyscrapers, avant-garde museums, luxury and dream palace airports, and many other civil engineering projects, e.g. sea bridges over

Box A

Technological history and its audience

1. In spite of efforts to promote technological history, it has so far attracted few devotees and only a limited readership. Among the many reasons for the lack of interest in it are the following:
- the very scope of works written on the subject, which inevitably is a patchwork of completely disparate and unrelated fields covering innumerable technologies and branches;
- the specialization peculiar to each technology is such that only a handful of technological historians are liable to take an interest in studying any particular branch;
- because of that specialization, the vast diversity of subjects which constitute technological history is further expanded by the number of chronological periods to be covered: the historian goes back ambitiously not only to the dawn of the basic mechanisms developed in the remote past, but also to the inventions of the Renaissance and the engineering achievements of the nineteenth and twentieth centuries ...

2. However, this history of electronic telephone switching consists of a confluence of favourable factors which, notwithstanding the above limitations, should enable it to find grace or even arouse interest among a would-be readership which is not merely confined to engineers in the particular branch of the industry concerned. There are also technological historians and communication sociologists. Indeed, this chronological outline of modern switching:
- firstly, points up the convergence that has taken place between three technologies that are now recognized as leaders of the modern technological advances, namely telecommunications, computers and microelectronics;
- secondly, because of the brief and recent period under review (1954–1989), the subject is still very topical;
- thirdly, it offers food for thought about the conditions which will soon shape the industrial future of this branch of telecommunications.

3. The account given in this work may also provide economic theorists with ideal material for a case study, being a perfect example both of a major technological shift in an important industrial modern activity and an oligopolistic market situation, that is virtually unique. For unlike the motorcar or oil industries whose consumers are legion, in the switching industry both the equipment manufacturing and the user elements, i.e. the public Administrations or private agencies which operate telecommunication networks, consist of a tiny number of leading partners and decisions makers: altogether there are a small number on either side of the seller/buyer divide, all the smaller fry being content to fall into step.

estuaries, tunnels under the highest mountains and giant dams with vast artificial reservoirs.

These modern monuments are "musts" on the list of every tourist visiting a city or country for the first time. They have become an essential part of what is known in the esoteric UNESCO'ese as "the common heritage of mankind". Nowadays, they are almost as universally familiar as the historical wonders we have inherited from the past. At an early age, school children become familiar with these latter day marvels through the pictures in their history and geography books and, more than ever before, adults are being brainwashed with their images through the press, television and publicity. Tourists flock to see them from all over the world.

When not being shepherded along by a licensed guide who tells him what he should admire, the alert tourist turns to his own pocket guide which describes all the details of his sightseeing tour.

2.2.2. The monuments of our modern world are not only concrete, steel and glass constructions built to last for centuries. Although far less conspicuous, there are also all the products of present-day engineering such as electrical and nuclear power stations, oil refineries and offshore drilling platforms, aircrafts, super-speed rail facilities and telecommunications.

Designed not for prestige, but for their usefulness, these monuments of technology are both, the essential economic foundations of our society and the indispensable servants of our every day existence.

Yet, their history is without glory and hardly known. Everyone takes all the facilities available in modern life for granted and few are interested in finding out how they came about.

2.2.3. Telecommunications are in the forefront of all the technical products which have undergone Blitz lightning development in the second half of our century. This is explained by the invention of microelectronics combined synergistically with an equally fast development in electronic computers, a branch now closely associated with telecommunications.

2.2.4. To anyone interested in the history of telecommunications, *this book* on telephone exchanges is *a travel guide* of the type tourists take with them when bound for famous monuments and sites.

Like any other travel guide, it does not claim to be exhaustive although too many pages altogether have accumulated in the drafting process. Only the outstanding features of the journey or a landscape are mentioned. Only relatively successful switching systems are described, i.e. those whose offspring have engendered a multiplicity of telephone exchanges all over the world. These are the active and vital ones that will continue to account for most of the operational exchanges on our planet until the beginning of the third millenium.

2.3. As in every good travel guide, the first part of the book is devoted to what must be termed "the archaelogy" of this technological history. It describes the origins and background from which electronics made its clamorous entry into the switching field in the early 1960s, causing such an upheaval in the state of the art.

3. The present-day role of the engineer

The role of the modern engineer is no longer the subordinate one of yesteryear. At that time, he had to sweat over trivial and routine calculations now effortlessly performed on a pocket calculator or personal microcomputer.

Now, his real role is to design, organize, elaborate and build.

These are noble functions which used to be the preserve of architects. Since the dawn of history under the Pharaons and the Greeks, the architect's function has always been held in the highest esteem. Eupalinos reflected carefully on his profession; he spoke of its nobility and his words have been echoed by thinkers of our own century [1]. There were also the architects of the Italian

Renaissance whose names will forever be celebrated.

Engineering work is, for the most part, fairly shortlived; it does not survive over centuries, yet it reflects the same art as the architect's. Engineering, in coming to mean "system design", draws ever closer to architecture.

Engineering is a difficult and demanding skill. Like the architect, the engineer has to deal with facts in contemporary trends and be familiar with the materials and components available. These are no longer stone, marble or beams but electronic chips or modern microprocessors. In addition, he must know how to arrange and place these materials in accordance with a logic which must first and foremost be strictly rational but leaves room for intelligence, artfulness and even imagination.

Knowing the rules of a sound methodology, whether for designing a switching system or a large-scale software program, implies a quasi-philosophical approach.

Anyone wishing to philosophize could scarcely do better than refer to the best sources, e.g. Bacon, Descartes (Discourse on the Method) [1)] and Boole (the value of his logic was to remain undiscovered for an entire century) [2)].

They are undoubtedly very fruitful lessons to be drawn from history. It is hoped that some of them will shine through this book even if they are scattered and underlying in an account which, after all, is more of a chronological than a didactic nature.

4. Some comments on the drafting of the book

4.1. Comments on what may appear as stylistic inconsistencies in a serious book

Readers accustomed to a greater uniformity of style in serious works may be disconcerted to find some passages of ostensibly minor interest in this book. They are asked to excuse these inconsistencies of style and priority: the authors were trying to avoid being unduly tiresome and this has been no easy matter in a book on a technique which is as specific as it is sophisticated.

Hence, some anecdotes to lend a light touch have been occasionally inserted to hold and refresh the reader's attention. Some of them are meaningful but, by and large, they are of minor importance. Their inclusion in an arid highly technical text serves to provide, as it were, oases like those stumbled across by caravans on their weary travels over the desert.

So, along with the descriptions of major technological shifts that have caused such upheavals in the structure of telecommunications over the past thirty years, we also offer a few sidelights from the corridors of a great technological history.

4.2. Picture of an exchange

Just like any other complex system, telephone exchanges and switching systems will be seen too much as abstract entities in this book. That is, indeed, an approach usually chosen by the engineer.

Looking at the serried rows of carefully enclosed modules on the racks or in the cabinets of an exchange is, in itself, a somewhat futile exercise which merely tells the visitor that a lot of money has been invested in that site and may show whether or not the exchange is in operation.

Owing to its complexity, therefore, it is not the physical reality of an exchange which the en-

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[1)] The three basic precepts given in "Discourse on the Method" are:
"– to divide every problem for examination into as many parts as possible and as are required for solving them;
– to place one's thoughts in order, starting with the simplest objects that are easiest to understand and gradually working up by degrees to an understanding of the most complex;
– and to make such complete enumerations and such general revision as to be certain of omitting nothing."
What better approach to the task of preparing system software or a switching system?

[2)] These are subjects and reflections which, as much as many others, and maybe even more so, would deserve to be inculcated at universities and institutes where high-level engineers train.

gineer must consider but simply its image as mapped out in his brain. Initially, this image is blurred but it becomes progressively sharper as successive developments etch themselves clearly into the outlines of his field of vision until, eventually, he captures the myriad of details involved.

Before this happens, however, the system's architecture, i.e. its skeleton, must be unfolded in the pages of the documentation in which it is described. A series of subtle dissections must then be performed to analyze an exchange's structure, penetrate the mysteries of its operation and assess its performance.

Working out the anatomy of a switching system is, of course, not comparable to the task of a surgeon or vet. There are no flabby parts or rounded pockets of liquid to be dealt with, but successions of black boxes and stacks of blocks and cubes arranged in a two or three-dimensional Cartesian geometry. These will appear as hierarchical structures arranged in more or less regular pyramids. Message carrying "pipes", sometimes called "buses", run from one black box to another and constitute the system's arteries and nerve tissue. To a layman considering an exchange diagram, the criss-cross configuration of these buses suggest the piping pattern of an oil refinery...

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CHAPTER I-2

HISTORY AND TECHNOLOGY
SOME BASIC COMMENTS CONCERNING THE CASE OF ELECTRONICS AND TELECOMMUNICATION DEVELOPMENTS

"*Every student of science should be an antiquary in his subject*"

(Maxwell) [1]

"*No thorough understanding of anything can be had without a knowledge of its origins, its roots*"

(Theodore Vail, Founding AT & T President)

1. In Technology, the virtues of its history

1.1. Too many engineers assume that before their time nothing of importance has happened in their field of activities. They are overwhelmed by the present state-of-the-art and are not interested in the past ... "This allergy of engineers to the history of their technology is too often inoculated in engineering schools and is intensified by the usual surroundings of bread-and-butter work during the rest of their professional life. Why should I worry about the past, when I can hardly keep up with the ever-changing developments in my profession?" [2].

1.2. Whenever a branch of technology is involved, scientific teaching, more often than not, offers ready-made recipes which, nowadays, run an increasing risk of becoming outmoded after only a few years. The situation is even worse when a teacher merely describes the present state of the art, i.e. equipment or standards, without giving any idea as to why things are as they are or without describing the phases through which the equipment and standards have been developed. Could there be any greater intellectual stimulus for the young student than to learn the reasons and essential facts underlying the state-of-the-art at the time of his study? Is there any better way for a teacher to hold a student's attention and help him remember his lessons than an ability to explain why and how things have evolved in a specific way?

1.3. A top athlete sportsman ready to enter championship competitions is familiar with the chronological list of the champions in his own field, as well as their records. Should the same not apply to the young engineer embarking on a technical career? It is for the ever-expanding generations of young engineers starting a career in the world of telecommunications, and even to a greater extent for the older ones responsible for teaching them, that this book is written.

Is any branch of history more exciting or astonishing than the history of technological progress? There we find all the triumphs and successes which have given rise to the "technical orthodoxies" recognized as valid at various periods. We also find, though usually passed over in silence, failures and abortive research which were either overtaken by other work or short-circuited by decisions made elsewhere. And besides the Nobel prize-winners and the holders of other distinctions in their own professional sphere, there are countless other engineers and technicians who have played an active and sometimes decisive part in developing a branch of technology but

who have remained anonymous and ignored, like unknown warriors left behind on the battlefield of their specialities.

2. Nomina numina ("names", "medals", that is: "names are like medals")

2.1. Latin is very concise. This play on two words differing only by a single letter has been passed down to posterity and is quoted in eloquent speeches on bright academic occasions, such as [3] ... It would be hard to imagine a more impressive way of conveying the significance of the honour conferred on a person by the mention of his name in the right place. Is there any finer homage or tribute in the military, for instance, than a citation for a deed of valour? Similarly, in professional – and rather prosaic – life, which is the lot of most engineers, the highest distinction for an individual is to have his name associated with a scientific discovery or a major achievement.

Therefore, in this work, due mention is made of the names of some personalities. Let us hope it will be justified, despite any fallibility on the part of the authors ... Two particular difficulties, however, have emerged in the drafting of the book.

2.2. First, there is an enormous number of people who, over the last thirty years, have taken an active and often decisive part in the development of switching. If all those who have with outstanding competence written articles on switching were referred to by name, whole volumes would not suffice! The following facts will make this point quite clear:

a) Each year, dozens of specialized technical conferences, connected to some degree with our subject, are held throughout the world, each attended by hundreds, if not thousands of participants. The alphabetical list of authors heading the conference "proceedings" will often contain as many as two or three hundred names.
b) If an anniversary occurs commemorating research on a subject, articles retracing the background of the research are published in reputable telecommunication reviews, and the number of bibliographic references at the end of such a review often exceeds a hundred or even twice as many.

In this book, relatively few bibliographic references have been used (they appear, separately for each Chapter of a Part, at the end of this Part). They were added either to draw attention to articles and works of prime importance, or substantiate statements which may have otherwise been considered arbitrary or controversial.

2.3. The second difficulty lies in the anonymity in which most of the research and development work involved in the design of a switching system is carried out nowadays [4]. In the pioneering days of switching – until about the 1920s – it sufficed to be liberally endowed with ingenuity, even without the comfort of solid material and financial backing, to become an "inventor" and to have one's own name associated with a given invention. Since the 1920s, this has no longer been the case; a system was no longer considered as an accomplishment of only one person. At the same time, it was unusual for one person to understand all the aspects of a new switching system, particularly those of the common control variety. However, designers of the different parts of a system were still acknowledged – at least, internally by the development organization.

With the advent of electronic switching, requiring cooperation between hardware and software, the identity of the designers of particular systems has become lost. There were still individual inventions within a system, but frequently they were attributed to many inventors. The broad concepts of new systems have been patented and do bear the names of individuals most responsible for the concept. However, these patents lack the kind of details one needs to produce a functioning system. Furthermore, names on patents are not as well recognized as those who receive public acclaim among their peers.

The design and implementation of switching systems has become, essentially, a collective undertaking, involving hosts of engineers and, today, an even larger number of programming

experts. We now have an anonymous group, serving merely under the banner of an enterprise. As a result, there are very few names of personalities who, because they happened to have directed a successful project, will be fortunate enough to emerge from anonymity and reap the harvest of public recognition [4].

3. Periodization in history and the successive generations of present-day electronic systems

3.1. The process of dividing a long period of past time into different consecutive sections is a historian's most habitual practice. It is the process he uses to characterize the various sections of the chronological divisions he has established, for instance, according to:

- changes in a political system;
- dynastic successions or presidential terms ("the reign of ..."):
- the great eras of our civilization ...

To designate this process of division, historians have coined a specific professional term, namely "periodization", which is concise and therefore convenient. Since "periodization" exists and could not be clearer as a concept, we shall use this term occasionally, for instance, whenever we describe the changes undergone by the different generations of switching systems. According to the accepted practice, generations are identified by a serial number, which is the one generally assigned to them but which will, of course, be duly explained and justified. And unlike the dynasties of Pharaons in the history of ancient Egypt, the serial numbers of successive generations for the areas of activity (switching systems, computers, electronic components, etc.) mentioned in this book do not go beyond the 5th generation, owing to the relative modernity of their technologies.

3.2. Boxes A, B and C indicate the more generally accepted "generations" for:

- the electronic computers
- the solid state electronic components
- the electronic switching systems

as they are referred to in the technical literature and in this book.

Box A

The Electronic Computer Generations

1st generation, with tubes	> 1945
2nd generation, with transistors	> 1958
3rd generation, with Integrated Circuits	> 1963
4th generation, with microprocessors	> 1975
5th generation, with "Artificial Intelligence"	1990s (?)

Box B

The semi-conductor / solid state components generations

– transistors	(1950–...
– first integrated circuits	(1970–...
– LSI (Large Scale Integration)	(1975–...
– VLSI (Very Large Scale Integration)	(1980–...

Box C

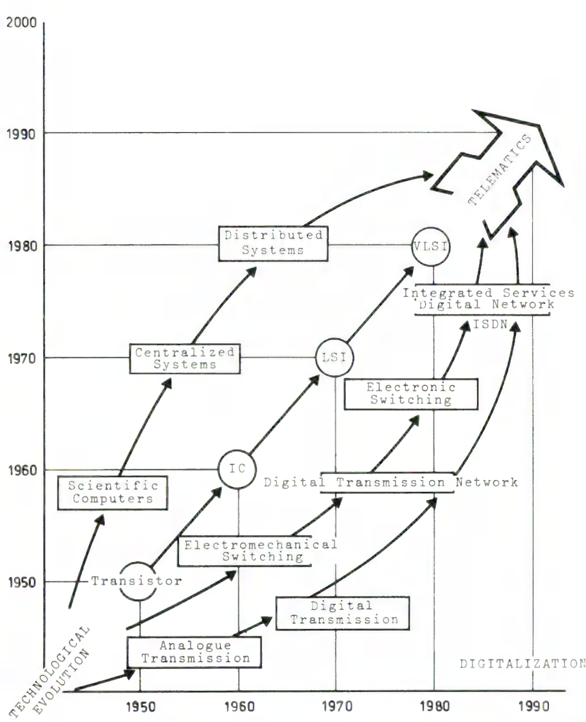
The generations of electronic switching systems

1st generation (1965–1975):	Space-division SPC
2nd generation (1970–1985):	Time-division digital *centralized* SPC command
3rd generation (1980–...):	Time-division digital *distributed* SPC command

3.3. Better than any description or table, the graph in Fig. 1 provides an immediate picture of how the different technological generations have contributed to telecommunications development over the 40-year period from 1950 to 1990.

The graph first came to prominence in the early 1980s when it was widely disseminated by its author Dr. Kobayashi, Chairman of NEC, and known world-wide as a tireless lecturer and an active champion of both:

- and his Company's slogan "C.C.C." (Communications, Computers, Components).
- the concept of the "new information society",



Evolution of telecommunications in the 1950-1990 period

Fig. 1

4. Consensus-based scientific knowledge. Orthodoxy at a particular period of history

4.1. Sociologists concerned with the history of science and the "*modus operandi*" of scientific research have developed a theory according to which all science depends on the sharing between scientists of the knowledge that they make public – hence, the major importance of "publications". A corollary to this thesis or an acknowledgement of the relativity in time as to what should be regarded as scientifically valid, is the assumption that scientific knowledge at a given period represents, in the final analysis, nothing but a form of social consensus between experts in the sector concerned [1].

4.2. Science and technology are certainly connected and interdependent (the second depending on the first) although quite different in character.

[1] It follows that scientific research operations would be reduced to a system of information exchange, whereby "contributions" are rewarded by a recognition of the status and fame of their authors. This concept of an all-embracing "potlach" among the members of a kind of "tribal community" formed by all researchers in the same branch of science is certainly pragmatic, but will, undoubtedly, be regarded as unduly prosaic.

Technology depends on industrial circumstances whereby production and cost factors are as important and maybe even more important than performance levels, notwithstanding the increasingly rigorous quality standards required by ever-narrower precision tolerances and the efforts made to keep the quality/price ratio under constant control. Yet, all these considerations are insignificant with respect to scientific research.

4.3. Despite this intrinsic difference between pure science and technology, the above-mentioned epistemological theories concerning science are nevertheless applicable to the analysis that should be carried out when describing the status of a technology at a given period.

Every period is characterized by what can best be described as "technological orthodoxy". This orthodoxy is being constantly challenged and therefore valid only for a certain period, which may be designated as that of a "generation" of equipment.

The term "technological orthodoxy" is not part of the "epistemologists'" usual vocabulary, and they may well consider it as a neologism. Yet, the word "orthodoxy" clearly expresses the intended meaning, under the rules of Greek etymology. "Orthodoxy" means "right doctrine", or a sound doctrine recognized as such because it is universally accepted by experts on a given subject (their "consensus").

The concept of orthodoxy, in fact, merely conveys the existence of the stratifications in time which historians have identified and catalogued as such, from time immemorial, for instance, in referring to the Bronze or Iron Age or, with regard to architectural techniques, in describing the Gothic and then the Romanesque period.

4.4. Until the beginning of our century, the phenomenon of technological orthodoxy was blurred. For a particular technology (construction of buildings or bridges, manufacture of steam engines or electrical machines, etc.), there was no clear-cut point to fix the onset of a period of production according to the rules – or "canons" – of technological orthodoxy and the point of completion when a different technology took over. Indeterminate periods of transition between two stages of technical development could readily be counted in decades.

4.5. In our time and age, the pace of means of communication such as:

- air travel, which boosted the number of international meetings,
- the instant dissemination of technical publications, which proliferate and reach readers all over the world,

has completely changed the development rate of various techniques. Upheavals giving rise to new generations of equipments can now be determined for a period of only a few years. The "key years" marking these upheavals can be identified much more accurately. Yet, the assignment of a date – the year 19xx – to a shift in technology orthodoxy is largely symbolic, for it merely identifies the universal recognition of the usefulness of a new technical method: its application and general introduction may take years, and a large-scale penetration of equipment manufactured according to a new design may not occur for as long as a decade.

4.6. With regard to the chronology of technological innovations and what can sometimes be described as inventions, a comment relevant to this volume may be useful. Despite the care taken in listing the most authoritative and then selecting the most characteristic publications or those with the best claim to precedence, there is, nevertheless, invariably some element of uncertainty in technological chronology. What dating system should be adopted? The date at which a discovery was made? The date when the patent claim was filed? The date of a publication (generally after the date of the patent, if any)? An analysis of prior claims which may be upheld against a patent application is a matter for the patent authorities, who are bound to have the last word. Few patents, except for some which have become famous, are mentioned in this volume and reference is, generally, made to the relevant publications listed in the bibliography.

Another comment of a more general rather than editorial nature concerns the emphasis on an invention or patent as the fruition of an idea which being already in the air ultimately assumes a tangible shape after a variable gestation period. An individual is identified by his date of birth, but this event does not occur for about nine months after his parents have met!

5. Technological Developments: not only a sequential chronology but also a complex web of intervening factors

5.1. Like any other branch of history, the history of technological development has by its very nature to be written sequentially, as a function of time. Yet, if a description were to evoke any interest, it should not confine itself to a purely linear approach (with the years as abscissas) or be a simple chronological record of the successive technical stages through which the technology had developed.

Conversely, the chain of developments must be woven into a complex web which is in fact a dual one:

- the first consists of all inputs – both new tools (including such intellectual tools as mathematical or logic algorithms) and new products ("components", "memories", etc.) – which eventually give rise to substantial innovations;
- the second web shows how advances stimulated by these innovations have occupied their rightful place in our economic and social environment and demonstrates their impact.

5.2. The latter aspect, i.e. the economic and social implications arising from technological innovation, and the considerable extent to which telecommunications have developed over the past few decades, will be dealt with in Part XI of this book.

Parts III and IV concentrate respectively on those developments which ushered in:

- the first electronic computers at the end of World War II and the prodigious expansion of the computer industry since then;
- the transistor birth as a result of advances in theoretical physics during the pre-war decades, followed by the extraordinary technological explosion which from the 1970s onwards led to the industrial production of solid-state components, integrated circuits and microprocessors.

Fig. 2 (in which the time scale is to be read from top to bottom) schematically illustrates the interactions that have taken place over the years between:

i) advances in theoretical physics,
ii) the birth of the transistor and its subsequent development in the form of integrated circuit,
iii) the electronic computer industry,
iv) and telephone switching.

The justification for inclusion of Parts III and IV in the book resides in the need for a description in a work on technological history – a description far more detailed than that offered in Fig. 2 – of the chronology of developments in the above mentioned first three fields i) to iii). The authors consider such an insertion of subjects not directly related to telephone switching as an important aspect of a true picture of the major interaction between sciences, technologies and industries, in issues affecting the telephone switching industry between 1954 and 1989.

However careful the authors' drafting of them, Parts III and IV do not pretend to be either exhaustive or authoritative since each of the fields covered could provide material for a shelf of historical tomes. Moreover, a fair number of well-documented works have already been written about them, with only a few mentioned in the references to the different chapters of Parts III and IV.

Lastly, *a word of advice to any switching engineer* reading this book who is likely to be *more interested in switching systems than in the history of technology.* For his benefit, the authors recommend that he simply study Figure 2 and skip Parts III and IV to resume his reading at Part V.

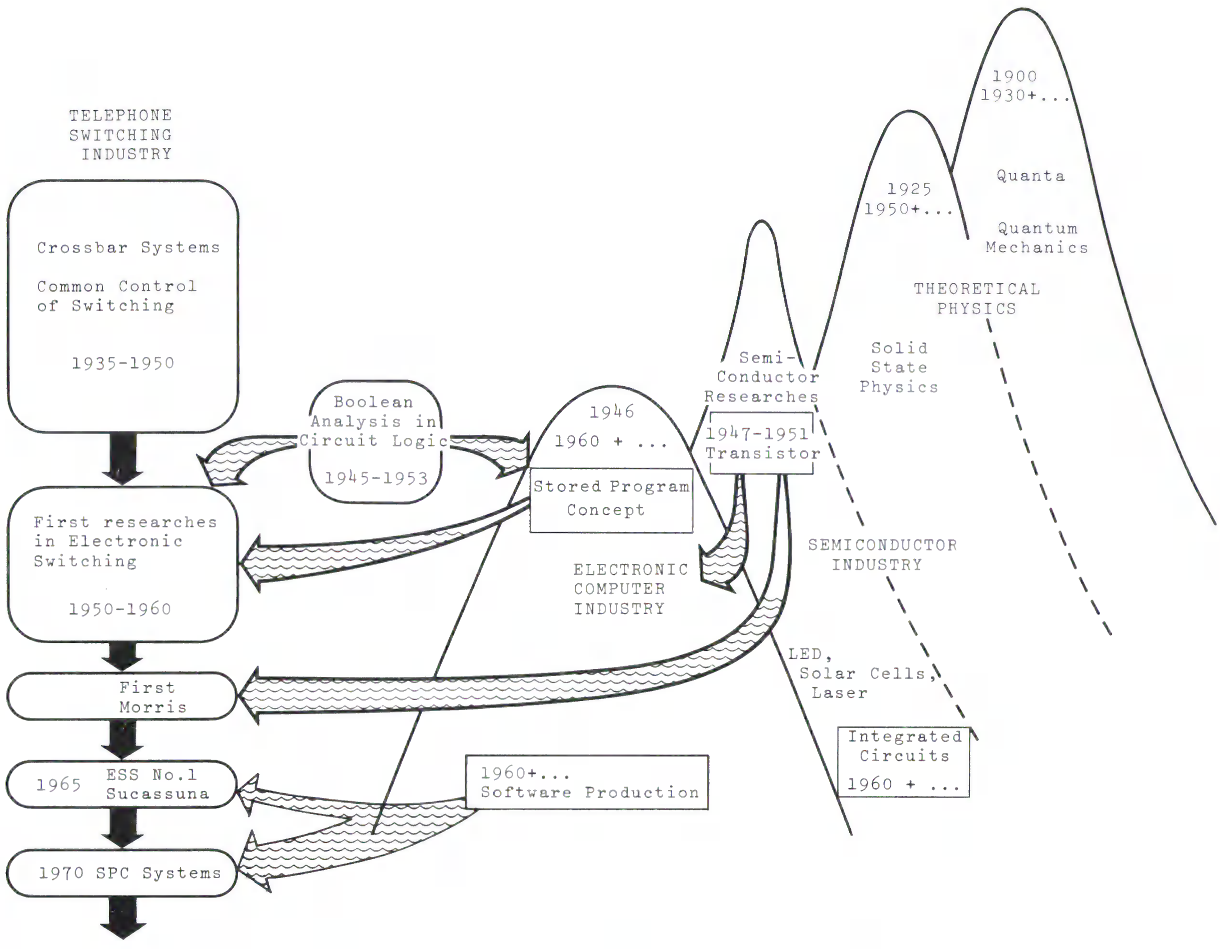


Fig. 2. Interactions between theoretical physics, semiconductor researches, electronic computer industry and telephone switching industry.

6. Telecommunications and Telephone Developments in the last 35 years

6.1. To split the century-old history of telephone switching into two periods – pre-1954 and post-1954 – as was done in two volumes may, at first sight, seem an arbitrary division. If we look closer, however – and it is the purpose of this Volume II – we must admit that the telephone and telephone switching changed more radically in the 1960s, 1970s and in the first half of the 1980s than in the preceding 70 years.

These 25 years bear witness to a true technological revolution distinguished by an explosive development, profound changes in network structures and a whole series of significant events.

1) Telephone networks expanded considerably:

- in terms of subscriber numbers: in 25 years, four times more subscriber lines were connected to exchanges than there were lines existing prior to 1960;
- in range: in almost every country, the *long distance* service has been automated and thus is one of the most popular with the general public. Once a luxury reserved for a small minority, the *international* service has now won over the man-in-the-street. In 1960, the *inter-*

continental service was no more than an embryonic facility open only on a few rare routes whereas by 1980 it, too, had been automated and extended to every country in the world. With traffic growth rates of some 20% to 25% per year, it has become an activity rightly regarded as a major economic factor.

2) The structures of telecommunication operating services, especially for telephony, which for over 50 years had remained conventional and unchanged were completely overturned, particularly in the early 1980s and onwards.

3) Telephone exchange design was radically overhauled. The spectacular number of inventions and innovations introduced in those 35 years exceeded by far anything that had occurred in the previous 70 years. As a result, the design of switching systems underwent a fundamental change. Formerly an engineering activity which before 1960 demanded experience acquired over many years in a highly specialized and largely mechanical profession, switching is now a genuine scientific discipline requiring a mastery of both electronics and computer software.

6.2. In the technical progress of telecommunications, two turning points are discernible:
- in the 1960s, the *abolition of distance*: a worldwide access for the telephone: a shrinking of the world!
- in the 1985s, the *conquest of time*: the success of digital time-division techniques in both transmission and switching.

The two years 1960 and 1985 will be referred to in Part XI ("Scanning") to describe the relevant situations of the telephone development at their time and the radical changes in the organizational structures of both Telephone agencies and Switching manufacturing industries.

Whenever electronic switching is specifically involved, the interval between 1960 and 1980 may be divided into two equal and clearly distinct periods:
- the 1960s, a period of "youthful enterprise" in which research branched out in every possible direction;
- the 1970s, a period of "vigorous maturity" matched in many countries by an upsurge of telephone demand.

6.3. Telecommunications did not begin to engage the attention of the general public until the 1970s through:
- a growing number of articles in the press and, particularly, in mass-circulation weeklies;
- telecommunication exhibitions, drawing crowds of visitors and increasingly well presented [2];
- public relations services in telecommunication enterprises, often created from scratch, but gradually extensively developed.

Historians and sociologists may be interested in noting a phenomenon which may appear puzzling to the layman, and consists in an almost point-to-point coincidence between:
- the new awakening of interest in telecommunications among the countries of Western Europe, and
- the first oil crisis of 1973, considered by the public as the beginning of the great economic crisis of the 1970s and early 1980s.

This is an observation which might be expanded in near philosophical terms. Without labouring the point but simply to indicate a line of inquiry, it might be suggested that this coincidence is a sociological reaction of sorts on the part of the West:
- an almost unconscious compensatory sociological reflex;
- an instinctive reaction (although with long-term effects) triggered by the shock felt in Western countries when in 1973, as a result of the disruption in their traditional oil supplies, they had to face up to a situation of extreme dependency as regards energy resources;
- a reaction which within a few years was astutely exploited by some statesmen, in the awareness of the pressing need to reorient their countries' industrial policies and promote the

[2] Especially the International Telecommunication Exhibitions organized in Geneva at four-yearly intervals under ITU auspices since 1971: Telecom 71, Telecom 75, Telecom 79, Telecom 83, Telecom 87.

expansion of industries less vulnerable to energy shortages.

Bibliography

[1] Quoted by J.J. Fahie, in "A History of Wireless Telegraphy", William Blackwood and Sons, Edinburgh and London, 1901

[2] I.E. Mouromtseff, "Of what value can a study of the history of his art be to the engineer?", Electrical Engineering, November 1949, pp. 945–948

[3] The preamble of the address with which President Leopold Senghor (Senegal) was received at the French Academy by Mr. Edgar Faure in 1984

[4] R.W. Lucky, Celebrities as engineers, IEEE Spectrum, Sept. 1987, p. 8

CHAPTER I-3

LANGUAGE ISSUES

"The learned man has the right and the duty to use an obscure language comprehensible only to his fellows"
[Umberto Eco: The Name of the Rose, p. 89]

1. The Language of Switching

1.1. Like any technology, telecommunications and, in their context, switching use their own highly specialized language. Some even call it a "jargon", which is not very flattering, since the term has an undeserved pejorative implication. Switching vocabulary is, in fact, very strictly defined and uses a highly formalized syntax in order to avoid ambiguities in equipment descriptions. As in any language, the denominations are either old expressions sanctioned by usage and hallowed by time, or newly-coined words etymologically conforming to all academic rules (it will be noted that this vocabulary contains a number of nouns and adjectives with Greek roots). National as well as international committees, and among the latter the CCITT Study Group for Vocabulary, working in close coordination with the International Electrotechnical Commission (IEC), keep a strict watch over these vocabularies and definitions.

(Professional societies and other institutions follow other procedures for drafting and publishing telecommunication vocabularies. These are frequently part of the input to the CCITT process with respect to international terminology agreements but have little or no international standing: they are useful only in their native country.)

The task of establishing formal definitions is very difficult. This has been common knowledge from the most ancient times. It was a subject which occupied great philosophers and writers (see Box A).

For the uninitiated, the language of switching may appear esoteric and confusing. To technological historians who are not specialists on the subject, the main terms which might arise difficulties and which are used throughout this work are listed in a Glossary at the end of the volume. The Glossary contains the definitions of these terms taken from the official list of CCITT definitions. (See also section 4 and, for acronyms, Box D and section 5 of this chapter.)

1.2. Any technical language must of necessity follow upon technological developments. It should even precede them: before equipment is produced, the concepts governing its implementation should be clearly defined and established. Yet this is often not easy for those who have to draft specifications and descriptions of new types of equipment.

Since switching techniques have undergone extremely rapid development during the past 30 years, indeed, a real conceptual upheaval, the corresponding development of their language can be followed practically step by step by referring to the innumerable technical articles and the less numerous books written on the subject. These publications contain new words, acronyms and abbreviations, some of short existence, swept away or replaced by others, while some take root and survive. An historical knowledge of terminol-

Box A

How to define a thing.
Some considerations on the proper use of definitions
(historical references)

1. Aristotle (384–322 B.C.) in "Sophist. Elench., Lib. 1, Cap. 2, T.1.": To define a thing is to make its nature knownby characteristics which preclude its confusion with anything else.

2. Pascal (1623–1662). "De l'esprit géométrique":
The true method of establishing definitions consists of three main things:
- never to use a term without first having clearly explained its meaning;
- never to assert a proposition without demonstrating it by already known truths;
- to define all terms.

The only definitions recognized in geometry are those which logicians call nominal definitions, that is to say, solely the assigning of names to things clearly designated in perfectly well-known terms; and these are the only definitions of which I speak.

Their utility and purpose is to achieve clarity and economy of discourse by expressing in the single name assigned something which could otherwise be conveyed only by several terms; yet in such a manner that the name assigned be bereft of every other sense that it may have, preserving only that sense for which it is solely designed.

3. Lewis Carrol (1832–1898). "Alice in Wonderland – The Turtle Soup":
"When I use a word", Humpty Dumpty said, in a rather scornful tone, "it means just what I choose it to mean, neither more nor less."
"The question is," said Alice, "whether you can make words mean so many different things".
"The question is", said Humpty Dumpty, "who is to be master,- that's all."

ogy should play an important role in the making of new language choices. Denominations introduced on the emergence of new technical concepts often seem to be outdated and obsolete after only a few years. It will suffice to encounter them in a text to establish the date of the document and the stage reached by the technology of that period. A semantic – or, rather, a semiotic – study of material published during those 25 years might serve as the sole subject of a student's thesis or of a book, which would not be lacking in interest. This volume, however, contains only a few allusions to certain changes in the rhythm of the language or its most characteristic inflections that took place during this period. A student of the language will be able to discern the appearance of fashions, popularly known as "fads": a particular subject, requiring a whole series of specialized terms for its description, may be fashionable for several years, but will hardly be mentioned four or five years later, when a different topic monopolizes general attention as reflected in technical publications.

1.3. In the technical language of telecommunications and switching, there are, finally, what may be called "buzz words", i.e. the favorite keywords in the jargon of the initiated. They are constantly used in the spoken or written technical language. They consist of nouns, numbers or, more esoteric still, acronyms. The entire vocabulary of these buzz words is quite small: a knowledge of about twenty of them will suffice for the author of any official speech to lend it the most effective technical coloration. As examples of these buzz words, we shall mention:
- among the words, those appearing in Box B;
- among the principal numbers, those appearing in Box C;
- among the most frequently used acronyms, those appearing in Box D.

Box B

Some "buzz" words of the 1980s

Architecture	Environment
Module	Interface
Analog	Digital
Compatibility	Crosspoints
Synchronization	Synergy
Software	Program
Memory	Distributed
Protocol	

Geostationary orbit

Box C

Some magic numbers

1. First of all, as a general rule, those corresponding to the power of 2:
   - 8: the "octet", sometimes abbreviated as "o", i.e. a set of eight bits (a "character"), too often wrongly called a "byte" * in the technician's jargon;
   - 32: e.g., the number of channels in one of the two standard PCM systems;
   - 64: e.g., 64 kbit/s for the bit rate of a digital telephone channel or 64 ko for the capacity of a high performance integrated-circuit memory;
   - 256: e.g., 256 ko for an even higher performance memory;
   - 2048: e.g., 2048 kbit/s for the bit rate of a primary PCM multiplex.

2. Apart from this series based on binary numbering, some other numbers, a knowledge of which will suffice to give an impression of highly technical connotation, such as the number 36,000 (very easy to remember ...) being in km the height of the geostationary orbit above the Earth's surface.

3. The (sometimes not too well known) terms denoting the units of measure:
   - nano = 10^{-9} (e.g., the nanosecond = 10^{-9} second);
   - pico = 10^{-12} (e.g., the picowatt = 10^{-12} watt, or 10^{-9} milliwatt, milliwatt being the usual reference unit for expressing power in telephone transmission).

* The origin of the word "byte" was for a long time regarded by many as mysterious. In fact, it is merely a popular term coined in 1956 to designate the set of bits that a computer can swallow at once, in one mouthful, instead of absorbing the bits sequentially, one by one. The number of these associated bits was not necessarily 8, but was sometimes more, whence certain ambiguities in the exact interpretation of the widely-used word "byte". The official term "octet", to which Anglo-Saxon terminology was allergic to for a long time, is nevertheless beginning to replace the term "byte" in the language of the better technical reviews.
For further details concerning the etymology of the word "byte", see W. Bucholz, – Origin of the Word Byte, in Annals of the History of Computing, Jan.1981, p. 72.

Box D

Some of the most popular acronyms
(see also section 5)

1) Those used to characterize integrated circuit components:
   MOS (Metal Oxide Semiconductor)
   LSI (Large Scale Integration)
   VLSI (Very Large Scale Integration)

or memories:
   RAM (Random Access Memory)
   ROM (Read-Only Memory)
   EPROM (Erasable Programmable Read-Only Memory)

2) Those used in telecommunications:
   IDN (Integrated Digital Network)
   ISDN (Integrated Service Digital Network)
   LAN (Local Area Network)
   PBX (Private Branch Exchange)
   PAM (Pulse Amplitude Modulation)
   PCM (Pulse Code Modulation)
   TSI (Time Slot Interchange)

3) Finally, words for which no one knows whether they are:
   - acronyms such as BORSCHT used to designate the device giving digital access to an analog station set and providing the functions of:
     - Battery feed
     - Overload protection
     - Ringing
     - Supervision of the line's on-hook/off-hook status
     - Codec for coding and decoding analog voice signals
     - Hybrid (2/4-wire conversion)
     - Test
   - or words coined in accordance with all the rules of lexical innovation by coupling a prefix and a suffix:
     the first, chronologically: the "BIT" (BInary digiT) which is so widely used nowadays that it is merely a word in common use;
     the "MODEM" (MOdulation-DEModulation) and the "CODEC" (COder-DECoder);
     or, more recently, the "PIXEL" (PICTure ELement).

2. The origins of the word "electronics"

2.1. The word "electronics" is so common that it may be assumed to have entered the vocabulary as early as the beginning of this century... In reality, it did not come into everyday usage until the end of World War II. Language purists will insist on differentiating between the common noun "electronics" and the adjective "electronic".

2.2. The noun "electronics", a newly coined word, did not come into use until the 1950s. Its meaning has by now become so self-evident that any definition would seem to be superfluous, whether it be used to denote the particular sector of the industry concerned or a specific field of engineering.

2.3. As early as in the second decade of this century and even more so, since the 1920s, the adjective "electronic" was known to and used by professionals in the different branches of telecommunications: radiocommunications, radio broadcasting, and long-distance telephone communications. These professionals formed a rather closed circle, however: during the 1920s they were a few score in number, and during the 1930s no more than a few thousand all over the world.

A more restricted use of this adjective by professionals existed also in the past. It was mostly used in conjunction with the word "tube", and the term "electronic tube" came to be accepted as a composite word [1].

3. A difficult problem in switching terminology: "space-division switching and time-division switching"

3.1. A fundamental distinction must be made between two basic types of switching: "space-division", and "time-division".

The difference between these two kinds of switching is clear to telephone engineers, but must be explained here for the benefit of non-initiates. This is indeed why in every work devoted to switching these two types are defined at the outset – as is done here.

Several attempts to endow such definitions with official status have been made by calling upon learned gatherings – such as meetings of Study Group XI of the International Telephone and Telegraph Consultative Committee (CCITT) – attended by the leading experts in this domain. But it is no easy matter to produce a definition which is both precise and easily understood ... (Nothing is more difficult than trying to get general agreement among a group of eminent persons as to the exact wording of a definition which meets those two desiderata: each member of the group wants to have his say, and there is always the risk that such a definition may be subject to a somewhat devious, if ingenious, interpretation.)

3.2. Without wishing to usurp the position of the official experts in terminology, and in consequence, more with a view to giving "explanations" rather than drafting formal definitions, we shall describe here the two types of switching as follows. To do this, we shall refer to what constitutes the "speech path" between the inlet to an exchange ("incoming line") and its outlet ("outgoing line").

3.2.1. *Space-division switching* systems are those in which the speech path is continuous through the exchange (e.g. as when an entirely metallic circuit, including metallic contact crosspoints, is used): each established speech path is consequently spatially separated from all other speech paths.

Such a continuous speech path, once set up, remains unchanged for the whole duration of the telephone communication.

3.2.2. *Time-division switching* systems are those in which the telecommunication messages are separated from one another in time and use a common physically continuous connection (e.g. a metallic connection) known as a "bus", "highway", etc.

Time-division implies that speech information is sliced into a sequence of time-intervals ("time slots"). Each time slot corresponds to a "sample"

[1] As a "doublet", the term "electronic tube" (which became later "electron tube") was wholly appropriate as far as academic style was concerned but engineers who found its length somewhat irksome used the single word "tube" amongst themselves. Traditionally, it is in distinguished academic circles that a name is attributed to anything new, and these circles always prefer a name made up of several words, or else a polysyllabic word (e.g. "telecommunications"!). And it is no less a tradition that, in the natural evolution of each language, such long expressions or words come to be shortened by half, after they take root and come into general usage. Thus, in English, "motorcar" has become "car" while, in French, "voiture automobile" was first shortened to "automobile" and then to "auto".

of the speech information. In most time-division systems these samples have been the subject of a quantization and, in the case of pulse-code modulation (PCM) systems, of digital coding of the quantified values.

3.2.3. Remarks relating to both 3.2.1 and 3.2.2

The foregoing explanations, relating to telephony by reference to "speech information", also apply, *mutatis mutandis*, to the switching of any other kind of information.

3.3. Time-division switching and digital switching

3.3.1. In switching terminology, there is a widespread tendency to make no distinction between "time-division" switching and "digital" switching, the two terms being considered virtually synonymous in everyday language.

Given the technology of the 1980s, the equating of these two terms is – in most cases – quite acceptable. But, strictly speaking, the term "digital switching", if so used, is, as we shall see, simply a convenient shorthand for the longer but more precise "time-division digital switching".

3.3.2. To clarify these ambiguities in terminology, we cannot do better than reproduce the following definitions (Nos. 714.14.06 and...0.7) from the International Electrotechnical Vocabulary published by the International Electrotechnical Commission (IEC) and which differentiates between these two types of switching:

"digital switching: switching of discrete-level information signals" and

"analog switching: switching of continuously varying information signals".

3.3.3. Time-division switching, as described at 3.2.2 above, can be either analog or digital. It is digital only if the samples of speech information referred to in 2.2 are composed of discrete levels, as is most frequently the case – indeed almost universally at the period when this book is being written. Hence the questionable but current fusion in everyday technical jargon, of the terms "digital" and "time-division" as alternative adjectives to describe this type of switching.

3.3.4. It should be noted that space-division switching also allows the transfer of information in the form of discrete signals, whether speech information in quantified form, or data transmissions. It is therefore necessary to state that, strictly speaking, switching systems exist in two domains:
- analog/digital
- space-division/time-division

The various types of switching should accordingly be set forth as in the following table:

Nature of switched signals	Switching Division	
	Space-division	Time-division
Analog	(3)	(4)
Digital	(2)	(1)

where (1): time-division digital switching
(2): space-division digital switching
(3): space-division analog switching
(4): time-division analog switching.

Note: The most common cases are (1) and (3). Case (4) corresponds to PAM (Pulse Amplitude Modulation) switching. An example of (2) can be found in protective facilities for digital transmission lines.

3.3.5. Now that these basic notions have been explained [2], the present chapter should record a further complication in the terminology relating to digital time-division exchanges. When such an exchange is of some size, the basic components of its switching network are twofold:
- elements for time slot interchanges – or, more correctly, stages ("T-stages") of time-division

[2] In addition to space-division and time-division switching (which use multiplexing in physical space and in time, respectively), mention should, for the sake of completeness, also be made of a third type of switching, namely one based on a frequency-division multiplex. Although such a type has on occasion been envisaged, and although there have even been some attempts to make a model, it remains, at the present state of technology, a purely theoretical concept, without practical application. (See for more details section 4 of Chapter II-1). The term for general use in the United States for "toll" is currently "interexchange carrier (IXC)" as compared with "local exchange carriers (LECs)".

switching –, by which logical and memory devices effect the desired changes of time intervals, and

- "S-stages", in the form of matrices which effect space-division switching between the inlet "bus" and the outlet "bus" carrying information-samples. (A feature of switching thus achieved by S-stages is that it is specific to one such sample and that it is not the same for any other sample: the connection points of the S-stages are dynamically controlled according to the timing rate of the time-division multiplex).

4. Some terminology (and spelling) differences in English usage

4.1. In Volume I (p. 18), the author noted differences between British and American English used in *terms* (and *spelling*) for telecommunications. "For 80 years or more, telephones on either side of the Atlantic constituted two worlds apart. English telephone network terminology thus betrays considerable differences between even the most common designations, depending on whether British or American English has been used."

Due to the strong presence of the United Kingdom in standards bodies in the past, British terms have become engrained in English international literature on telecommunications whenever used outside North America.

In writing the present book for an international readership, terminology choices sometimes presented its authors with a difficult task.

For *spelling* consistency throughout the book, the task was rather easy with the wonderful facilities now offered by word-processing machines and it was decided to adopt American usage: the double "l" was dropped from signalling, the "me" from programme, the "ue" from analogue, and the "re" at the end of center was reversed.

In choosing the *terms* to be adopted, the authors had to compromise: American terminology was used when descriptions relate to an American environment; in all other texts, British terminology was used, corresponding to the official publications (e.g. CCITT books) in international telecommunication literature.

4.2. Some explanation is needed here since occasionally American and British English terms are irreconcilable and may lead to confusion.

A most important term in this category is "*exchange*". Outside America, the term is synonymous with the "central office", or simply "office" of American usage. In North America an exchange is the geographical territory served by one or more central offices where the same tariffs apply.

Other irreconcilable English terms are "*trunk*", "*junction*" and "*toll*".

In British and international usage, "trunk" relates to an interurban service between distant towns and is equivalent to the American word "toll" [3]. The expression "long-distance" can be regarded as equivalent to both the British "trunk" and the American "toll" and is used often in this book whenever necessary to avoid the tiresome confusion between trunks and tolls.

In British and international usage, "junction" is used to designate a circuit linking two exchanges in the same local network. In North America, the corresponding expression is "interoffice trunk".

5. For the layman, some additional explanations on acronyms

For the layman, four acronyms which often appear in this book should also be explained.

[3] Various terms, such as "toll", which have been extensively used in North America over the years are gradually being eliminated with the changes in regulation and the introduction of competition into the public networks. In this book these terms are still used whenever a differentiation has to be made between earlier developments of systems intended for applications at the time. The term for general use in the United States for "toll" is currently "interexchange carrier (IXC)" as compared with "local exchange carriers (LECs)".

5.1. The first of these technical acronyms is the one of PBX. Private Branch Exchange (PBX) is the switching equipment installed on the premises of (generally) a business or governmental office to service the "extension telephone stations" in that place.

There is a very wide diversity of designs for PBXs, notwithstanding the similarity in nature in their design, compared with the one of public exchanges. These are not a specific topic of this book which concerns essentially the switching exchanges of the telephone service agencies: Administrations or Private Operating Enterprises.

5.2. Another acronym which will appear throughout the book is SPC for "Stored Program Controlled" (exchanges).

5.3. When we shall come to *digital* time-division switching or when we refer to the present-day digital transmission system(s), the acronym "PCM" will be used for Pulse Code Modulation. Its opposite, "PAM" for Pulse Amplitude Modulation, designates a technology of the 1960s for time-division *analog* systems,

5.4. Finally, the now most popular new acronym is the famous "ISDN" which means "Integrated Services Digital Network".

Part II

The roots of Electronic Switching (1935–1950)

CHAPTER II-1

ELECTRONICS AND THE SWITCHING TECHNOLOGY (1935–1950)

1. The technology of switching

1.1. As covered in Volume I [1], switching since its beginning had a technology of its own. Whether it was the coordinate copper peg bus bars (Fig. 1) or jack and cords with plugs used by operators or the gross and fine motion electromechanical switches used in automatic telephony, the technology of switching was developed to be unique to this selective function.

During the 1910–1930 decades the formulation of principles applicable to switching system design was a slow evolutionary process. It is only in the 1930s and 1940s that appeared the algebra of logic applied to the design of switching circuits [2,3] and to their optimization [4] and that improvements in congestion theories were applied to the evaluation of switching networks [5], etc.

In the early 1930s, the concept of general purpose hardware began to appear. Various types of functional units were constructed from relays, the difference between these units being in the circuit design details. This was the beginning of switching system design in which system functions and structures, not hardware characteristics, were the important considerations.

1.2. Great strides had been made in the field of transmission when scientific and mathematical theories were applied to it in the early 1900s. The theories of Maxwell and Heavyside together with the invention in 1912 of the thermionic vacuum tube by Lee De Forest [Vol. 1, p. 107] were to provide tremendous progress in telephone transmission.

The invention in 1927 of the negative feedback amplifier by H.S. Black of the Bell Laboratories made possible the simultaneous transmission of a large number of speech signals over a single pair of wires, the technique known as "multiplex transmission".

1.3. In switching, progress was not made on the basis of scientific inquiry but by electromechanical inventions. These inventions constituted a body of knowledge that represented the state of the art. By the end of the 1930s some researchers began the classification of this knowledge about switching devices and systems. Such classifications of knowledge are the start of scientific investigations. This approach made possible new directions in the art of design and invention in switching.

For the first time, engineers knowledgeable in the various switching system arrangements were philosophizing about these system "principles" [6]. As a result, new types of study activities and, for the first time, the more fundamental research and exploratory development activities began to appear in the efforts of the switching engineers. The advantages of introducing speed as a factor into the control of switching systems were indicated as a way to the future. Speed could be obtained by considering the application of electronics.

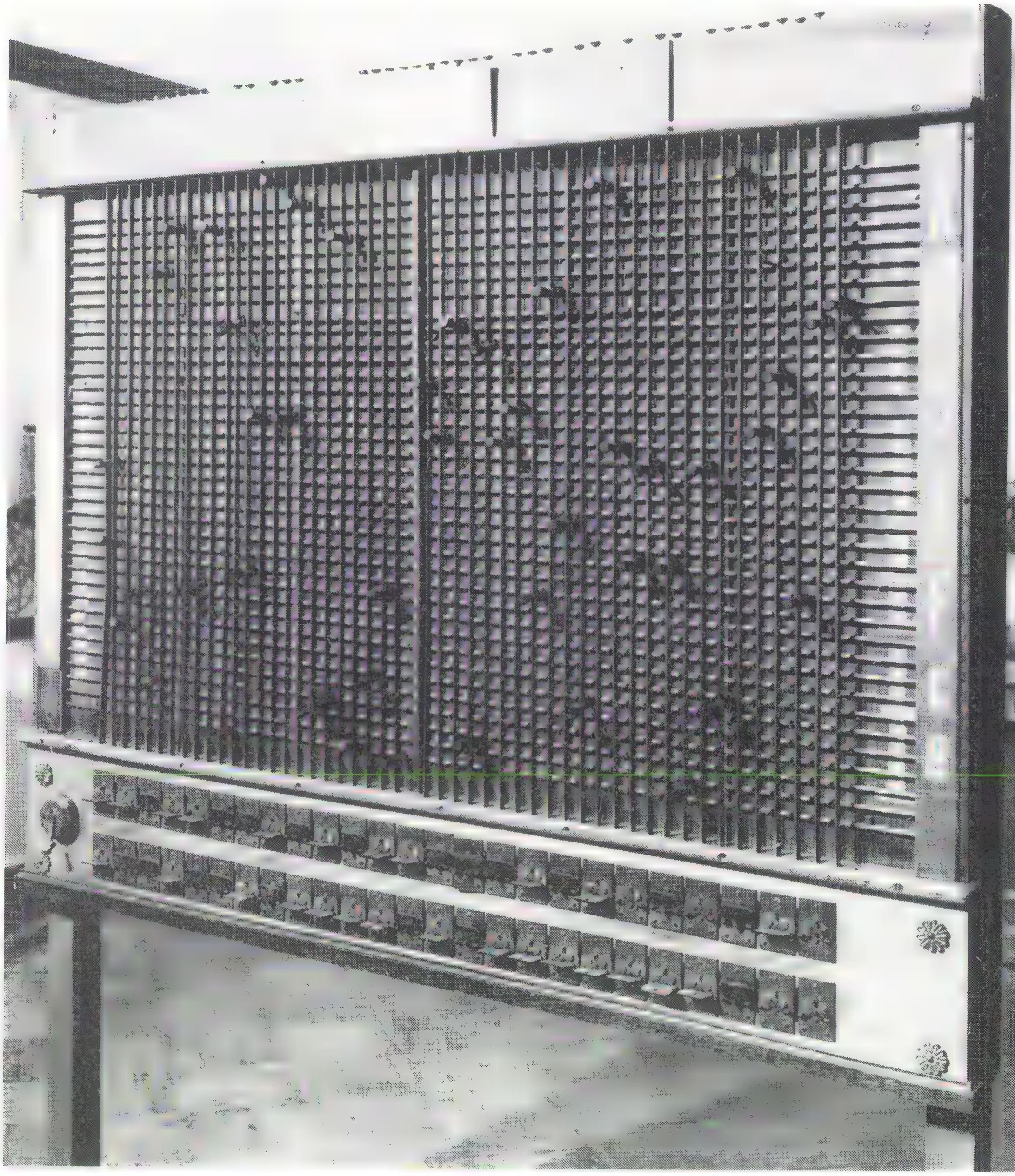


Fig. 1. A 1882 Western Electric switchboard installed the same year at St-Petersburg (Russia) and carefully conserved in the Communications Museum of the PTT administration of USSR, in Leningrad

2. Electronics for logic

2.1. *Could vacuum tubes do the job?*

Besides the moving switches that provided the connectivity in electromechanical switching systems, the general purpose tool that provided the logic for the designer of these systems was the ubiquitous relay. Electromagnetic relays were known from the early days of telegraphy for their ability to repeat, regenerate or amplify the

telegraph signals as they made their way over longer and longer lines.

The success of the vacuum tube as the work-horse for modern efficient transmission from 1912 through World War II, used for the basic transmission functions of amplification, modulation and oscillation, became an inspiration to research engineers seeking new ways to accomplish the switching functions.

The established common control techniques in switching required many relays for logic. Due to their relative slow operating speed, electromechanical systems required a plurality of controls for typical exchange switches serving ten thousand lines. These controls were made possible by the use of hundreds of relays, some with as many as ten contacts.

Researchers postulated that by using tubes in place of relays a high speed control could be devised thereby reducing the required number of active controls. However there was one difficulty in applying thermionic electronics to switching. To implement this approach would have required thousands of tubes. Each tube had a filament or heater that consumed at least a watt of power. Despite the invention of the multielement vacuum tubes, the continuous power and heat dissipation of thousands of tubes [1] would for the life-time of the switching office incur a very large expense that would in time more than offset any relay savings.

The invention of the transistor (see Part IV) towards the end of the 1940s was the big breakthrough that was to make this early dream a reality. But this major event was more than a decade to come when engineers first experimented with the application of electronics to switching. Various methods were however already proposed in the 1930s and 1940s to use electronics and tubes for logic, e.g. by W.T.H. Holden in Bell Laboratories [9].

2.2. *The Electronic Bistable Circuit*

With relays, memory was relatively easy to achieve by employing an extra contact to "lock" them operated, thereby remembering the passage of a momentary pulse [10].

Vacuum tube electronics was most useful in amplifying analog or continuously varying signals. It was also used for generating continuous oscillating wave signals. The first important step taken to employ vacuum tubes in logic and memory circuits was the invention in 1919 by Eccles and Jordan of the flip-flop circuit [11]. The flip-flop circuit is a one bit memory or first stage of a binary counter. Initially it required two separate vacuum tubes and therefore was used very "parsimoniously". Multi-stage binary counter circuits were devised for use in nuclear physics research in the 1930s. Hot gas tubes (thyritrons) were used in Cambridge (UK) by F.C. Williams in 1932 [12]. The first electronic computers depended upon the use of vacuum tubes for logic. It was quite natural that physicist John W. Mauchly played a leading role in the design of ENIAC [13], the first electronic computer machine ever in service.

2.3. *Beam Switching Tubes*

As early as 1936 patents were appearing proposing beam electron tubes to perform the basic switching function of selection. The idea of electron beam tubes came from the maturing television industry where all-electronic devices were beginning to successfully replace the Nipkov disk approach. Generally these proposals were for the use of these devices in place of electromechanical selectors. Multiple beam selected targets were to be placed in the face plate of cathode ray tubes. References [14 to 18] provide references to some of these patents. Many of these early ideas came from Sweden. A photograph of one proposal, the

[1] The dissipation of heat from electrical components has been a constant struggle of electrical engineers. As smaller relays and other electromagnetic apparatus were designed it was necessary to insure that wiring faults would not cause them to overheat to such an extent as to start a fire [7]. When great banks of vacuum tubes were employed for carrier transmission systems precautions to prevent their premature burnout had to be taken to insure that heat was removed [8].

History is now repeating itself as engineers design greater numbers of components in micro-integrated circuit chips.

Box A

From "Evolution of the Technology", Vol. III of "LM Ericsson 100 Years" by C. Jacobaeus [20]

LM Ericsson's (LME) contribution to all-electronic switching dates from the late thirties. It was then that the possibility of replacing moving parts such as switches and relays by static, electronic components was first investigated. One attempt was a specially designed cathode ray tube whose electron beam could be locked on one of several multiple positions and used for speech transmission. The trial showed that it would be possible to make electronic switches but that they would be expensive and require much maintenance.

In the mid-forties LME acquired the license rights to the "trochotron", an invention of Hannes Alfven and Harold Romanus (Swedish Patent 146142). This was an electron tube in which an electron beam could be steered into one of ten positions under the influence of crossing electric and magnetic fields. Considerable sums were spent on investigations of the trochotron principle, but without real success.

(see Fig. 2)

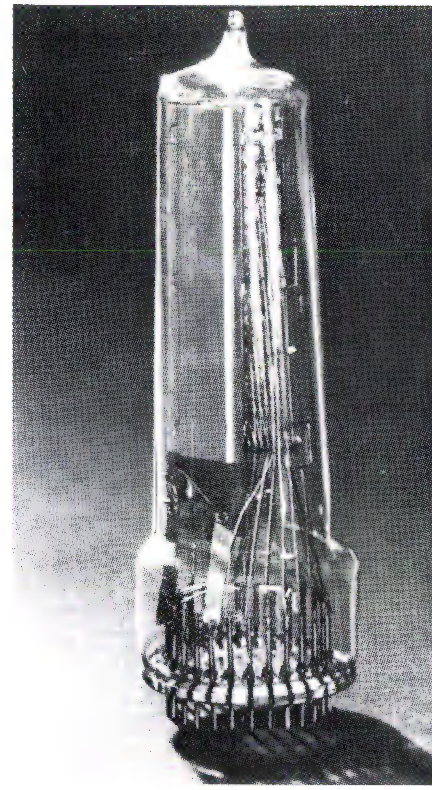


Fig. 2. The Trochotron (from [20])

"trochotron" and comments by a representative of L.M. Ericsson that acquired the rights to this patent are given in Box A. A quotation from an ITT author about other types of devices in this technology is given in Box B. Cathode ray tubes with metal contacts in the face were developed at Bell Laboratories for use in World War II projects [19].

2.4. *Exploring the Gas-Filled Tubes*

Hot cathode gas-filled non-linear diodes have been used in the power supplies of early radio sets. Telephone engineers first postulated on the use of gas-filled diodes that did not have a heater or filament and therefore did not consume continuous power. They were given the name "cold cathode tubes".

Box B

From "Digital Networks" – a manuscript (1982) by E.M. Deloraine

After 1937, the ITT Laboratories had searched for some novelty in switching, starting with the selector. Trevor Clark, for instance, had developed a commutator using a rotating electronic beam; Stanislas Van Mierlo has shown the possibility of switching light beams modulated by voice current, reflected by mirrors capable of orientation. These attempts, however, did not appear to have real merits.

The preliminary developments carried out in the ITT Laboratories prior to the war (World War II) had shown that in order to introduce electronic components in exchanges it was essential to take advantage of their high speed of operation.

The first important application of these tubes was by AT & T in the telephone ringing circuit in 1936 [21]. Placed in series with the low impedance bell magnet, they provided a high impedance isolation of the magnet for protection against surges occurring on the telephone line and responded very well to the high voltage used for the ringing signal. The ringing signal circuit, that in the United States was frequently completed through a ground return for party line selective ringing, became more immune to line noise when these devices were employed. In the 1940s the gas tube was used in another ground return circuit to bring multiple pulse metering to the AT & T panel dial system [22a].

The success of the cold cathode tube in signaling applications encouraged inventors, to apply this form of electronics to the logic circuits of switching systems. Many experiments were conducted and patents obtained. Also since the maintenance costs for mechanical devices used in registers or senders were high, many proposals were made to use gas tubes as counters and memory devices for such applications, principally in the United Kingdom [23], in Belgium (BTM in Antwerp) [24] and in the Netherlands [25].

While there was much experimentation with gas tubes, they did not find extensive use in switching systems prior to World War II.

After the war the great switching development in the USA was the No. 5 Crossbar System [1a, 26]. It used gas tubes in association with timers and as a detector for a unique magnetic memory known as the "Dimond" ring translator [27] (see Box C).

Since there had been much pre-war effort on gas tubes, a research project was established at Bell Laboratories to explore the development of a small community dial office that would use only crossbar switches and gas tubes. This system, identified as the No. 385 Crossbar System, was built and demonstrated in 1948 [22b], just as the transistor was announced.

Sealed contact or reed relays had been successfully used for certain wartime applications. Some application of these devices was then being made in switching, including experimentation with them as crosspoints. Gas tubes were used in combination with sealed contacts in some of these proposals [22b, 29] to implement a new control technique, known as "end-marking" (see Box B, section 2.3 in Chapter II-3). Other experimentation then was directed towards the use of gas diodes as the crosspoints themselves rather than to control crosspoint relays [22c]. The most famous experiment was in the first stored program controlled switching system, the Electronic Central Office (ECO) that was placed in service in Morris, Illinois, in May 1960, where gas di-

Box C

The "Dimond" ring (invented in 1945)

Thomas L. Dimond was a designer at Bell Laboratories. In seeking an improved method for translating from equipment location to directory number in that portion of the AMA (Automatic Message Accounting) system [1b, 27], known as the "Number Group" [28], he invented a circuit using large rings enclosing electromagnets. Loose wires were threaded through the rings. Pulses sent through the wires were detected by gas tubes associated with the electromagnets. Most appropriately he gave his translation scheme the eponym, "Dimond Ring".

(see Fig. 3)

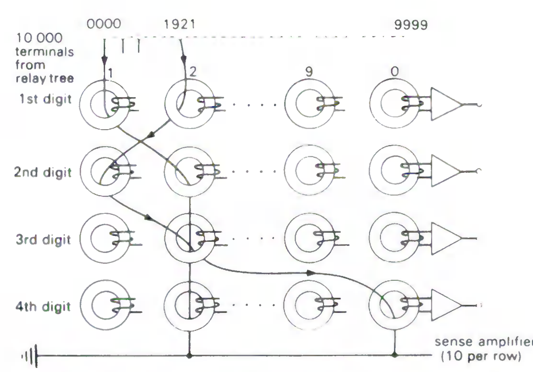


Fig. 3. A schematic figure of the Dimond rings

odes were used in the speech path of the switching network (see Chapter II-4).

Many others in Italy, Japan, West Germany, the Netherlands and the United Kingdom postulated and experimented with new types of these devices, searching for a system that would use a switching network with non-metallic non-moving crosspoints (see Chapter II-5).

3. Electronics in signaling

The most successful application of electronics to switching prior to World War II was in the area of signaling. Ringing signal detection with gas diodes described above is only one example. Up to the 1920s all supervisory signaling to, from, and between central offices was accomplished by the use of direct current (dc). As the speech path was extended by the use of electronic amplification, or repeaters as they were known, dc signaling to alert operators in distant offices and to supervise connections was in a first period extended by the use of relaying or signal regeneration around the repeaters.

The 1930s were marked by the introduction of "tone signaling" (American terminology) – or "frequency signalling" (British terminology) – on long-distance repeatered circuits, specially on the 4-wire circuits. Before World War II (and even after), transmission engineers dealing with long distance operation were particularly active on these signaling developments. This trend was quite natural since signaling is a technology halfway between the fields of transmission and switching.

3.1. MFC Signaling

3.1.1. Volume I describes in detail a series of innovations which took place in long-distance signaling in the 1930s, and which were essentially based upon the use of signal receivers provided with electronic vacuum tubes. It was the origin of the "multifrequency code" (MFC) signaling system(s) in which the signals correspond to the transmission (in the speech band) of one or several simultaneously transmitted frequencies out of a set of four, five or six. This technique, after the 1950s, achieved considerable success and became the work-horse for long-distance signaling during a long period (up to the 1980s when "common channel signaling" (CCS) progressively took precedence over MFC signaling as the modern technique (see Part X). (MFC had its limitations including speed, format, absence of two-way signaling and, as referred to in Box D below (end of 3.1.3), potential for fraud.)

Research on MFC signaling was carried on in both Europe and the United States during the 1930s. Researches in Europe are covered in detail in Volume I [1c]. Some details on researches and field trials in the United States in the pre-war years are given here in addition.

3.1.2. When in the Bell System it became necessary to send dial or address signals over the speech path, difficulties were encountered due to the distortion such relaying introduced. Quite early, circa 1925, the concept of using tones in the speech band for signaling was proposed. The first applications of tone or alternating current to signaling were not necessarily to achieve "dialing over long distances", but to speed up dialing for operators. The use of rotary dials requires a minimum one or two seconds of operator time for each digit dialed. Considering the hundreds of numbers operators dial every day, various coding schemes were proposed to send digits per push-button signals instead of sequential sets of signals per digit that takes place with rotary dialing. While dc signaling schemes were devised that transmitted a digit at a time [22d], it was soon realized that since operators were to be the first to dial over longer distance toll lines or trunks, the use of tones to represent digits also reduced the call holding time on these lines that were then so expensive [22e].

The first successful system in the United States used one tone or combinations of two out of four tones in the speech band [29]. As with many other tone signaling systems of the times circa 1930, there was a stimulation not only by operator long distance dialing, but also by the prospects of customer toll dialing with the advent of automatic ticketing systems recording the call billing details.

In their early development phase, the Bell Laboratories engineers in 1940 operated a field trial of this technique in a Baltimore, Maryland, No. 1 Crossbar local office [1d]. This trial was a precursor of the more general application of multifrequency pulsing to local switchboards operating with the first No. 4 Crossbar system (toll system) in Philadelphia, Pennsylvania, in 1943 [1e].

A code signaling system devised in the United States, initially for operator toll dialing, was included in the new crossbar systems then under development [22e]. This signaling system employed only combinations of two tones out of

six tones. An important attribute was "self-checking". Only if a proper code was received could the call processing continue.

For the prototype in 1943 of the No. 4 Crossbar toll office in Philadelphia, Pa, the MFC signaling was adopted for transmitting the address information over some long distance circuit. It was the beginning of the lead that the United States in general and AT&T's Long Lines division in particular took in introducing voice frequency signaling into the public network. Later they pioneered in the use of single frequency (SF) supervisory signaling [22f, 30].

3.1.3. It was only at the end of the 1950s that MFC signaling prevailed outside of the United States: in 1956 in Japan; in the 1960s in Europe.

The two-out-of-six MFC system was gradually adopted throughout the world for interoffice signaling (see Chapter X-2). The MFC American code was used in the early 1960 for signaling over the first transatlantic submarine cables (the first "TAT1" laid in 1956, the second "TAT2" in 1959). This intercontinental signaling system was also used on the 1963 transpacific cable COMPAC connecting Canada and Australia.

At the 1964 CCITT Plenary Assembly the transatlantic system became the international standard signaling system CCITT No. 5. It has been the most widely used intercontinental signaling system to 1984 until common channel signaling started to be applied. One advantage of interoffice signaling over a separate common channel (a "data link") is that the telephone customer cannot simulate supervisory signals on the speech circuit used for his call to circumvent charging (see Box D). This type of simulation for theft of service had been made possible by the availability of low cost transistorized electronic signaling devices [31].

Box D

Theft of service

Electronic techniques in switching have been both used by those desiring to circumvent the charging or billing facilities as well as by the telephone engineer to prevent such thefts.

In the United States long distance calls have always been billed with complete details, such as the date, time of day, number called, call duration, etc. Initially, to implement the billing for direct distance dialed calls in electromechanical switching systems, a system known as Automatic Message Accounting (AMA) was developed [1b, 28]. The calling line number for the billing record was obtained by adding an operator to the connection to request from the calling customer the number of the line from which he was making his call. This number was keyed by the operator and added to the rest of the billing record for the call. This method of operation was known as "operator number identification" (ONI).

With this arrangement, it was not long before the public realized that the accuracy of the billing records depended upon the honesty of the callers. Unfortunately many charges were found to be billed to wrong accounts as a result of incorrect numbers being deliberately passed by callers to the ONI operators.

To insure billing accuracy, new equipment made possible by the application of modern electronic techniques and known as "automatic number identification" (ANI) was developed [1b, 32]. The ANI equipment automatically determined calling line numbers and placed this information onto the billing records. Several varieties of ANI equipment were developed. More than 37 million lines were equipped with ANI in Bell System offices, starting in 1961. Similar equipment was installed in the offices of independent telephone companies [33].

Electronics also aided those bent upon the theft of service. Long distance dialing had been made possible by electronics applied to interoffice signaling. The proliferation of literature on the subject made it possible for engineering students and experimenters to design their own signaling equipment that could imitate the interoffice signals. By persistent use of such signal simulators, known as blue, red, black and "cheese" boxes, it was possible to prevent billing of various calls in the North American network [31].

Equipment and accounting software were developed to locate such calls and to detect theft of service. With the introduction of common channel signaling, this particular practice became impossible on interoffice calls.

3.2. Signaling equipment for MFC senders and signal receivers

In 1954 the CCITT had standardized " one frequency" (CCITT No. 3) and "two frequencies" (CCITT No. 4) signaling systems for international service in view of the forthcoming European subscriber dialing. In both systems a dialed digit was represented by a binary code based on combinations of four time elements using the presence of the frequency (cies).

In most of the European countries and e.g. in the United Kingdom, the first applications of electronics in exchange equipment were for the signaling senders and receivers.

Initially signaling tones were generated by a set of vacuum tube oscillators common to all of the operator positions or senders. Vacuum tube receivers associated with the distant exchange detected and registered the digits for extending the calls. These functions became the first to be converted to the use of transistors. In fact, the first commercial use of transistors was in this type of signaling application [34].

4. Electronic switching tries to use transmission techniques

4.1. The search for applying electronics to switching took yet another direction in the 1930s. A number of system proposals were made to apply the principles of frequency-division transmission multiplexing for use within switching systems and, in combination with transmission systems, to obtain what today would be called synergism. Many of these suggestions utilized electromechanical switches to tune oscillators that were used for the modulators and demodulators that placed the calls on different frequencies of a common medium [35].

In the early 1960s, the desire for the integration of speech sampling and frequency-division transmission was revived with a number of proposals from Japan [36], U.S.S.R.[37], the United Kingdom [38] and the United States [39]. The system in the United States had the acronym ISAM for "Integrated Switching and Multiplexing". It was built and demonstrated by IBM in 1965.

While these forms of switching and their integration with frequency-division transmission were investigated and proposals made, they were discarded once it was recognized that space-division switching was required to implement frequency-division switching [40].

However, these proposals were the first suggestions for using a different medium than space to separate the call paths from one another within a switching system. Frequency-division was the forerunner of another common medium technique, viz. time-division.

4.2. In contrast to frequency-division switching, time-division switching, or "time separation switching" as some had called it earlier, has been a successful technique since the availability of integrated circuit techniques. Its successes began however only in the 1970s and derived from the "digital revolution" in telecommunications provided by the availability of "integrated circuit" components.

Analog time-division for switching was first proposed in the late 1940s. These experiments are described in Chapters II-4 (Bell Laboratories) and II-5 (outside of the United States).

"Digital revolution" of the 1970s and the long history of its origins and of the first attempts to digitize speech signals are covered in Part VIII of this book.

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CHAPTER II-2

A PHILOSOPHICAL VIEW OF THE STUDIES OF ELECTRONIC SWITCHING AFTER WORLD WAR II

1. The attempts which were started at the beginning of the 1950s to achieve electronic telephone switching were a great adventure. They were made in the firm belief by the research enthusiasts that "the future lies with electronics".

These enthusiasts had perhaps some difficulty in rallying their managers and top officials to this belief, i.e. those making basic decisions and approving the budgetary allotments which determined just what research was to be carried out. "Electronics" – a prestigious word which had only recently come into general use – was however a word then clad in every virtue. During World War II, technical supremacy in electronics had often been one of the factors determining the successful outcome of military operations. The decisive part that radar played in naval and air battles is a typical example, of which much was made by the media at the end of the war.

2. Apart from the enthusiasts' steadfast belief in the use of electronics for telephone switching – and from their shrewd intuition as to the direction which long-term developments would take – there was, however, little idea as to what orientation should be given to such research. Nor did one know when commercially competitive results in electronic switching might be expected. It was simply felt that it would take place in a fairly remote future. (There was also the traditional competition within a switching development organization for budget and personnel allotment. One should note that many of the "old-timer", switching's experts were not interested in applying themselves to the new electronic arts but instead tried to maintain the status-quo.)

Now that research in electronic switching has finally been crowned with success, one should not underestimate the limitations in the telephone exchange manufacturing companies that beset the switchgear industry during the post-war decades.

Except in the United States and Sweden, neither of which had suffered the ravages of war, the top priority of these manufacturers was, at the time, to deliver as quickly as possible telephone exchanges to replace those which had been destroyed by enemy action. It was also necessary for them to stay within the strict limits imposed by the financial provision for telecommunications allocated in tight national budgets. In each country, the telephone switchgear industry – hampered as it was by its purchasers' insistence on minimum prices – was very traditional in its commercial operations: its potential clients were few in number and in most countries orders for public telephone exchanges depended, in many cases, on a single purchaser. It was, in fact, these purchasers who determined the switchgear industry's policies in the fields of research innovation and investment.

Notwithstanding all these limitations and the uncertain prospects of electronic switching, major studies were launched.

3. Let us employ a metaphor once more

World War II had led to rapid progress in a wide variety of technological fields. An idea of the situation during the period 1945-1955 can best be obtained by comparing it with the progress which was made in navigation towards the end of the fifteenth century.

As is well known, it was in 1492 that the King of Spain decided to send Christopher Columbus and his caravels westwards across the Atlantic on an expedition to find a new sea route to the Indies and Asia.

Christopher Columbus thought he had reached India when in fact he had discovered America. That had not been the purpose of his voyage – but it changed the course of history.

3.1. The earliest research in the field of electronic telephone switching had been along two main lines:

- an attempt to develop an electronic connecting point, a magic device which would supersede the good old metal contact provided by electromechanical relays; and
- the development of an electronic selector, based on the idea of deflecting an electronic beam, more or less as in the cathode-ray tube used for radar screens and in television sets which had just begun to come into public use.

3.2. The studies and research aimed at developing commercially viable telephone exchanges had a definite aim – *to provide the telephone subscriber with new facilities at a cost which would be competitive* with that of existing electromechanical exchanges.

To emulate the flexibility offered by the operators of the manual service (a flexibility which was often missed by subscribers after their transfer to automatic switching) and to be freed from the rigid constraints imposed on automatic switching by the relatively primitive "logic" of the electromechanical exchanges were the bright prospects offered by research managers to those who had to decide the future of the telephone service – that is their financial authorities.

3.3. The two main lines of research referred to in 3.1 were finally abandoned, since each ran into a dead end.

3.4. When the new facilities referred to in *3.2.* became available, and after their numerous advantages had been loudly praised to both administrations and subscribers, it had to be recognized that the latter were hardly interested: those who might have been expected to benefit from the innovations simply vanished, as if by magic, as soon as there was any word of even a small extra charge for the new facilities.

3.5. We can thus see that early research in the development of electronic switching was marred by:

- errors in the initial technical orientations,
- misconceptions in the assessment of the results to be achieved.

By analogy this was what happened to Christopher Columbus' expedition – but which led to his discovery, after his wanderings over the ocean, not of India but of America. It thus seems quite in order to compare:

- Christopher Columbus' voyage which, to the sailors on his caravels, seemed to be endless,
- the long march, steadfastly undertaken during 15 years in AT&T's Bell Laboratories in the United States which led to the first stored program controlled (SPC) telephone system, the one that started commercial operation at Succasunna, New Jersey, on May 30 1965 and was the first of the large AT&T "ESS" series.

3.6. Navigating was certainly not always easy during such long voyages to new shores. The crews of the caravels of Christopher Columbus were ready to mutiny to force him to turn back. In the field of switching, the financial authorities felt that these studies, aimed at bringing about a radical change towards electronics, were taking a long time, that their outcome would remain highly uncertain for years to come and, in particular, that the funds allocated were assuming simply astronomical proportions – at a time when millions of dollars were not disposed of casually.

4. Audacity and perseverence win.

4.1. When, in 1965, the Succasunna office was put into operation, technical publications throughout the world joined in celebrating this triumph with unstinted praise. In official quarters it was duly stressed that this was the greatest research and development project ever carried out by AT&T and its laboratories. This was in fact a rather coy way of pointing out that it had been the most costly of all those projects.

It is only natural that the publications issued by a company to record technical achievements and innovations resulting from the work of its research department down the years should confine themselves to the good news of the successful cases, and that they make scant allusion to all the difficulties which the research managers had to endure. It is to the excellent work "Telephone" by J. Brooks [1], a writer and professional journalist, in a book published to glorify AT&T but written with entire freedom, that one must turn for an inkling – from what was perhaps a somewhat acid pen – of the difficulties (including overspending and failure to meet deadlines)

Box A [1]

Unexpected size and cost of initial ESS development
(a story by J. Brooks, a professional journalist)

"Of all the new wonders of telephone technology – the one that gave Bell Labs the most trouble, and unexpectedly became the greatest development effort in Bell System's history, was the perfection of an electronic switching system, or ESS.

In the early 1950s, a Labs team began serious work on electronic switching. Kappel, in his first Annual Report as AT&T president, in the year 1956, wrote confidently, "At Bell Labs, development of the new electronic switching system is going full speed ahead. We are sure this will lead to many improvements in service and also to greater efficiency. The first service trial will start in Morris, Ill., in 1959." Shortly thereafter, Kappel said that the cost of the whole project would probably be $45 million.

But it gradually became apparent that the development of a commercially usable electronic switching system – in effect, a computerized telephone exchange – presented vastly greater technical problems than had been anticipated, and that, accordingly, Bell Labs had vastly underestimated both the time and the investment needed to do the job. The year 1959 passed without the promised first trial at Morris, Illinois; it was finally made in November 1960, and quickly showed how much more work remained to be done. As time dragged on and costs mounted, there was concern at AT&T, and something approaching panic at Bell Labs. But the project had to go forward; by this time the investment was too great to be sacrificed, and in any case, forward projections of increased demand for telephone service indicated that within a few years time would come when, without the quantum leap in speed and flexibility that electronic switching would provide, the national network would be unable to meet the demand.

Kappel's tone on the subject in the 1964 annual report was, for him, almost apologetic: "Electronic switching equipment must be manufactured in volume to unprecedented standards of reliability. To turn out the equipment economically and with good speed, mass production methods must be developed; but, at the same time, there can be no loss of precision..." Another year and millions of dollars later, on May 30, 1965, the first commercial electric central office was put into service at Succasunna, New Jersey.

After 1965, ESS was on its way ... But the development program, when the final figures were added up, was found to have required a staggering four thousand man-years of work at Bell Labs and to have cost not $45 million but $500 million. *"

* These views of Brooks are to be placed into perspective in Chapter V-1.

which must have arisen in AT&T and its Bell Laboratories during this project.

We reproduce in Box A with his kind permission and under his responsibility, Brooks' own account – undoubtedly based on information which he checked carefully.

4.2. There is abundant literature – see G. Mensch [2] for example – analyzing the different ways (such as "invention" and "innovation") in which technological progress is made. In respect of each essential factor, such a literature assesses the prospects of commercial success resulting from research. It analyzes the types of company in which major technological achievements of this century have had their origin and gives first mention to:

- the size and financial strength of these companies;
- the industrial sector concerned;
- whether or not they are multinational;

but does not omit to give suitable prominence to the managerial dynamism of those in charge of the companies.

The foregoing account of the lengthy path towards what was a technological revolution in the field of telecommunications – the introduction of stored program controlled exchanges – should rightly be considered as a tribute to the perseverance and energy of those who were responsible for that research.

4.3. When assessed after the intervening years, the time taken up by studies and research (and the time, no shorter, that was taken up by the industrial developments needed before Western Electric could start manufacturing the components of No. 1 ESS) do not seem to be unduly long – even if it may have seemed long to those in financial charge.

Mensch's reference [2] includes a table showing the average number of years needed for the development of a number of technological innovations [1]. The table covers the years 1945 to 1965, i.e. precisely the period during which the first electronic system which really deserves this designation, the SPC central office of the No. 1 ESS type, was developed and installed at Succasuna. The table distinguishes between two phases in development:

- the "incubation" phase; and
- the "industrial/commercial development" phase.

The average duration of these two phases, as given by the table, is nine years and five years respectively – making a total of fourteen years. This is precisely the intervals for the Morris and No. 1 ESS achievements. Therefore the time required before the No. 1 ESS system was launched may thus be seen as quite average, according to the Mensch's analysis.

5. Like a river which, as it runs its course, collects the waters of its tributaries, several of which may have come from distant valleys, a research project may, as it progresses, receive contributions from widely different scientific or technical fields.

A typical instance of such a confluence of different techniques is provided by the development of the first SPC exchange. The technical knowledge which contributed to that development covered:

i) the great amount of scientific and technical knowledge acquired by exchange designers and which included:
   - complete mastery of the centralized control of the "switching network" of an exchange, achieved since the operation of crossbar systems had been commenced [3];
   - the application of Boolean algebra to circuit analysis and logic studies [4] (see Box B), and
   - the conclusions which had resulted from studies of teletraffic, carried out in connection with the creation of switching networks (such as "link systems" [5], or non-blocking "CLOS networks" [6]),
   - etc;
ii) all the progress which had been made in the design and manufacture of electronic computers since their first appearance in the im-

[1] The Mensch analysis covers 40 "major technological innovations", of which 21 came from the private sector and 19 were from governmental bodies.

Box B

Applications of Boolean algebra to switching

1. Switching and computers make extensive use of logic circuitry. The invention of multi-contact relays in the 1920s accelerated the use of complex logic to design switching systems. The designers using pragmatic methods applied to these devices with great care and frugality. Generally their efforts were most successful and gave rise to the development and deployment of circuits such as the marker circuit for the No.5 Crossbar System.

In Volume I (p. 301) the evolution of more orderly and scientific approaches to the development of relay and switch circuit has been described. Generally after World War II the concept originated by C.E. Shannon ([4]) to use the so-called "Boolean Algebra", as well as tabular approaches such as the use of VENN diagrams, KARNAUGH maps and "truth tables" were gradually accepted as methods for the design of complex combinatorial circuits. Formal methods for the development of sequential circuit were also devised and used.

Without the use of these design tools the development of modern switching systems and computers – and later the development of integrated circuit chips – would not have proceeded as successfully.

2. Boolean algebra is well known to be perfectly adapted to the logic of relay circuits and binary devices. In this algebra only two exclusive states of a variable are permitted represented by:
- the closing or the opening of a contact (of a relay),
- the 1 ("logic one") or 0 ("logic zero").

The combinatorial circuits designed according to Boolean algebra use logic elements of the "gate" type to perform the three basic operations of this algebra:
1) the OR, represented by a plus sign between variables, such as A + B, which is read *A or B*.
2) the AND, represented by a dot sign between variables, such as A.B, which is read as *A and B*.
3) the NOT, represented by a bar over the variable, such as $\overline{A}$, which is read as *not A*.

Many textbooks were published in the 1955-1965 period to develop the theory and practice of Boolean algebra for circuit design. Electronic elements performing in this algebra both basic operations and intricate circuit arrangements have now become so standard as working tools that the engineer no longer thinks of the design behind the black boxes he is using for the logic manipulations he has to perform.

mediate post-war years. This included in particular the concept of the stored program and the memory devices that had been developed for the computers (see Chapter III-3);

iii) the evolution of the electronic components since the invention of the transistor in 1946 (see Part IV).

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CHAPTER II-3

1945–1955 RESEARCHES INTO ELECTRONICS FOR TELEPHONE SWITCHING

1. General survey of post-World War II research

1.1. Research into the use of electronics for telephone switching had been strictly limited before World War II; the war itself interrupted it completely. It was only in the second part of the 1940s and in only a few places that the telephone industry resumed its research:

- in the United States: at the Bell Laboratories
- in the United Kingdom: at the GPO Dollis Hill Research Centre
- in Sweden: LM Ericsson
- in Belgium: the BTM Company (Antwerp (see Vol. I, p. 201), an affiliate of the ITT Group
- in France: the LCT Research Centre of the ITT Group.
- in Japan: mainly at the "Electrical Communication Laboratory" of the newly established NTT.

Except perhaps at the Bell Laboratories, there was some scepticism about research in this field and what might be expected of it. A quotation from a 1974 lecture by C. Jacobaeus (the then Executive Vice-President of LM Ericsson) [1] typifies the feelings that were prevalent in the 1945–1950 period:

> "During the end of the 1940's, the telephone industry began setting laboratories – albeit on a small scale – for studying in more detail the possibility of introducing electronic components as essential building bricks in switching engineering. Relatively few people really believed that electronics would come to play an important role in telephone exchanges. In industry at that time the electronic laboratory activities in switching were in the nature of an insurance against unpleasant surprises."

1.2. In the electronics field, wartime activities had brought in many inventions and innovations such as pulse radars, computerized gun directors, and cryptographic devices. Field operations had proved the possibility of digitization of speech signals by pulse technique (see Chapter VIII-1).

A new generation of switching investigators came into being in the wake of the Second World War. Prior to the war, switching system designers were those who had grown up with the subject from manual to automatic electromechanical switching. This was a special breed of inventor-engineer operating in a field little understood by others.

Telephone transmission on the other hand had theoretical roots and engineering training in this field was possible in institutions of higher learning [2].

Returning from World War II were engineers and scientists fresh from the successful application of complex electronics. They were eager to use their new found talents in civilian pursuits, such as telecommunications. Pulse techniques were by then natural to them so that proposals were made in Europe [3] and America [4] to use these techniques in switching systems. It is interesting to note that they did not for sometime reconsider the wartime techniques of coded pulse transmission for commercialization. This resurrection did not take place until the late 1950s, more than 10 years after the invention of the transistor!

1.3. The invention of the transistor at Bell Laboratories in 1947 was the event that stimu-

lated the imagination of system promoters. But to a greater extent, the introduction of the junction transistor, which came into industrial production in 1954 was the event that triggered off earnest efforts and serious proposals by designers to study and experiment with electronic switching systems. At last there was the possibility of a reliable component that could be assembled in large numbers into systems without high power consumption and heat dissipation [1].

1.4. As covered in Part III, by the late 1940s the computer was coming into its own.

1.4.1. Since the number of vacuum tubes needed to build an electronic computer was much smaller than for a telephone exchange, much early progress was made here in the use of electronic logic and memory. For logic, tubes were used initially for computers, but with the invention of the transistor and other semi-conductors that were then developed, they were quickly adopted. For computer memories new devices were developed, viz. electrostatic cathode-ray tubes (Williams tubes), magnetic drums, and Forrester's ferrite core memories. These are described in detail in Chapter III-3; they provided research into telephone switching with very useful implements for the needed digital technology.

The interplay of technology developments between the computer and telephone industries may be very roughly summarized as a two-way affair:
- *telephone switching provided the logics* for computers, while
- *computers provided the memories* for electronic switching.

1.4.2. From the early days of the computer, there was a divergence of two disciplines, viz. hardware and software.

Hardware was a popular term used to refer to all of the physical components of a computer, viz., the tubes, relays, counters, and wiring. Software was a term coined by computer engineers to describe the non-hardware components, especially computer programs.

The software concept of "stored programs", (see section 4 of Chapter III-2), a familiar one in the computer industry, constituted by the mid-1950s the most important contribution of computer technology to electronic telephone switching.

1.4.3. The success of computer designs stimulated once more the thought that a single active control in a telephone office could carry out all of the many required functions for all of the lines. Several computers with serial architecture attested to the potential success of this approach.

1.5. It was the dream of marrying semi-conductor logic with computer memory that in the mid-1950s set teams in France, West Germany, Japan, Sweden, the United Kingdom and the United States to start exploratory development of electronic switching systems. Each had a different approach, a different combination of the electronic networks and controls. Probably at no time since inventors first tinkered with electromechanical switching had so many system design proposals appeared [6].

The research and development in *the 1955–1960* period are described in Chapters II-4 and II-5.

2. Preliminary research in the 1945–1955 period into electronics for telephone switching

2.1. After the Second World War, research in electronic switching was restarted in Bell Laboratories in the United States. After the successful design in 1946 of the No. 385 gas tube controlled crossbar system (see Chapter II-2, section 4), members of their research department started design experiments using a variety of electronic components and two principles of design philosophy:
- "line (and trunk) scanning",
- "end-marking" in the switching network.

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[1] "The fact that machines with thousands of tubes operated under field conditions is a great tribute to the computer engineers who developed them." [5]

(In recent years as smaller integrated components have become available, heat dissipation has returned as a problem. On the other hand, the number of discrete components has been reduced to the point where meer numbers no longer overwhelm system designers.)

2.2. Scanning [see Box A]

The scanning concept may be regarded as one of the first basic ideas that came to switching engineers when they attempted to use the speed of electronic devices for obtaining a time-sharing process to eliminate the need for a large quantity of line and trunk equipment.

Even in the pre-war period, between 1938 and 1940, engineers of the Bell Telephone Manufacturing Company (BTM) of Antwerp, in their studies of the Rotary 7E system, had set their sights on developing a high-speed (400 steps per second) scanner-line-finder switch. This switch of mechanical design was to be associated with an electronic vacuum tube unit, to detect call originations on subscriber lines, scanned four times per second by the finder switch. The scanner system was designed to eliminate the subscriber line relays (see Volume I, pp. 201–204). Scanning with these switches was however impractical since the contacts of the finder wore excessively.

By 1952–1954, the scanning concept was being used at Bell Laboratories in an experimental system known as the "Drum Information Assembler-Dispatcher" (DIAD) [7]. (DIAD was an experiment exploring the logic required to process telephone calls in real time with a single common logic unit). A capacitively coupled rotating scanner served in DIAD as the equivalent of both line relays and dial pulse detectors. The scanner operated in conjunction with (on the same shaft as) the DIAD magnetic drum memory. Each scanner- and drum-address represented a line or trunk and was called a "time slot". A common centralized unit could read and write in the time slot before going to the next slot. The memory bits in each time slot stored all of the information about the status of the associated line or trunk and the digits dialed by a calling subscriber. The time slots acted as many individual registers.

The scanning principle has been retained by most electronic switching systems designed to date, as a means for time-sharing the control. Scanning was to become a basic function in electronic switching, one universally adopted in the design of space-division switching SPC systems.

Although the technology and methods of controlling the scanning process has varied in different systems, it is basic to most electronic switching systems. The scanning function was to take place:

- initially, in specific units known as "scanners";
- later, when centralized control was established, in the central processing unit (CPU) as in AT&T's ESS No. 1;
- and later, in special units known as "signal processors" which relieved the CPU of routine tasks.

Box A

Scanning
(a Box for the layman)

A scanner sequentially interrogates the on-off hook condition of the line and trunk terminations at millisecond speed:

- to detect call origination requests, and
- during call processing, to detect dial pulsing.

A common scanner device may serve to detect line and trunk conditions for all or part of an exchange. The scanner addresses the termination at different speeds:

- at a lower sequentially scanning rate, e.g. every 100 milliseconds, to detect call originations or disconnects;
- at a faster scanning rate, e.g. 10 milliseconds, to detect dial pulse information. In many applications of this type the scanner is directed to specific active terminals.

The terminal states that are detected by the scanner are stored in an central memory used as a "scratchpad" for call information processing.

2.3. "End-marking" [see Box B]

The initial research experiment at Bell Laboratories from 1948 to 1951 resulted in the Electronically Controlled Automatic Switching System (ECASS) [8]. This system centered on

Box B

End marking

Distinctive electrical signals, known as "marks", are applied to selected input and output terminals of a switching network for the purpose of establishing a connection between them. With "end marking", only one of a possible plurality of idle paths through a multistage switching network will be selected.

When marks, usually of different potentials, are applied to the selected terminals, a connection will be established. Possible parallel idle paths will be "locked out" from use and connections to other active paths prevented. This process is known as "end-marking".

At the end of a call, different marking signals may be applied to at least one of the two terminals to release the established connection.

taking advantage of the speed of electronics by employing high speed signaling and a switching network employing relays controlled by gas tubes. The ECASS switching network used a new technique termed "end-marking", that eliminated much of the interstage control wiring then commonly found in switching networks employing matrices of crosspoints.

3. In 1945–1955, another line of research in electronic switching: pulse time switching and first attempts at time-division switching (see also Chapter II-5, section 3)

The first *pulse-type switching* proposals were patented by both, in 1942, L. Espenschied of Bell Laboratories [9] and, in 1945, E.M. Deloraine (Fig. 1) [10,11], ITT Technical Director for Europe and at this time a refugee in the United States from German occupied France. These inventors used pulse gates to pass pulsed voice signals through switching stages much like a step-by-step system, with line finders, selectors and connectors.

Although amplitude pulses were used, the paths through the switching gate stages were closed continuously, that is there was no multiple use of the paths such as by time-division.

Several *time-division proposals* were made. The first one was in 1945 by E.M. Deloraine, together with P.R. Adams and D.H. Ransom of ITT (Federal Telephone and Radio, FTR, at Nutley, NJ.) [12]. Another was by T. H. Flowers of the British Post Office Research Laboratories at Dollis Hill in 1948 [13]. While these proposals using pulse amplitude modulation were viable in principle, the required large number of components made them impractical. Deloraine published his ideas in a doctoral thesis in Sorbonne [14] and internal company documents. He described switching by pulse displacement, (which today corresponds with "time slot interchange"), whereby information from a line is delayed in a memory until it can reach another line. Flowers also published the first of a series of papers describing these principles of electronic time-division switching [3,15].

By 1951 the ideas of Deloraine aided by Messr. Aigrain and Van Mierlo reduced to practice in a model [16] designed in the "Laboratoire Central

Fig. 1. E.M. Deloraine

des Télécommunications" (LCT) of ITT in Paris. This 100-line model was the basis for system "A", the first of three ITT pulse-type electronic switching models over the succeeding twenty-five years. Derived from the earlier Deloraine patents, this system provided multiplex pulse amplitude paths through two stages using an amplified bus technique that divided the two directions of transmission. One stage acted as a line finder and the other as a connector. There were 16 channels or what are now known as "time slots" that represented the multiplex positions in which pulses could appear. The sampling rate was 10 kHz. The cycling time slot memory was provided by gas tubes using binary encoding.

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CHAPTER II-4

THE 1955–1960 PERIOD RESEARCHES AND FIELD TRIALS IN THE BELL LABORATORIES

1. From Research to Field Trials

The system ideas described in Chapter II-3 were all in the environment of laboratory experiments.

At Bell Laboratories, the stage for a bold step was set to undertake the development of an electronic switching system that would eventually be placed into commercial service. This step was taken at a time when there appeared to exist a critical mass of new techniques resulting from laboratory switching experiments, from exploring the capabilities of the transistor, and from the progress being made in the infant computer industry.

At Bell Laboratories, initial studies were undertaken by a group led by a visionary by the name of Chester E. Brooks. Brooks came to the Systems Engineering organization from the New York Telephone Co, where he had been responsible for their fundamental planning. In 1949, he raised the interest of the top management at Bell Laboratories, particularly the President Mervin J. Kelly, suggesting that electronic switching had reached a point where it should be taken out of research and a development project should be undertaken. From the beginning, the "ECO" (Electronic Central Office) project, as it was then entitled, set large scale goals. The visionary that he was, Brooks liked to talk of systems requiring only "50 flip-flops" to run an office of as many as 500,000 lines. In the context of today's VLSI circuit chips, the time may not be too distant when 50 chips will accomplish all of the required functions of a host office of this size. One of the authors, (AEJ), was a member of this original study group. The group set out to study not only the technical but also the economic feasibility of electronic switching.

As these system engineering studies matured, the management in 1952 established under W. Keister a development organization to explore the possibilities of building working models for those basic building blocks that had emerged from the systems engineering studies for ECO as well as for other applications. An exploratory development group was established to build this experimental electronic switching equipment.

Exploratory electronic switching development work in Bell Laboratories went forward on several fronts. Included were control appliques for electromechanical systems, remote line concentrators, and electronic switching systems for PBX and central office applications. They were similar to efforts undertaken elsewhere at a later date to use electronics to solve pressing service problems in extending switching for nationwide applications. While these development projects were all of significance, they met with varying success. The following section concentrates on the most important and fruitful of these projects, the one initially entitled the "ECO" project.

2. The ECO (Electronic Central Office) Project of Bell Laboratories [1,2,3]

2.1. Technology was moving fast. By the end of two years of exploratory effort, 1952–1954, it became obvious that a full development of ECO was in order. A development organization was established under Dr. C.A. Lovell, a mathematician who had been a principal contributor to the successful anti-aircraft gun directors of World War II. (These ballistic directors coupled radar and analog computers to beat back the invasion of German V1 "buzz bombs".) The initial authorization was for $45 million. Ultimately, 500 million US $(1965) were to be spent before the first line of production equipment was to be placed into service in 1965 [4]. (The writer (AEJ), who was the originator of the initial authorization, had moved in 1952 from the systems engineering to the development organization.)

The system as then conceived consisted of:

- a switching network of gas tube crosspoints (Fig. 1),
- a "Barrier Grid" storage tube (Fig. 2) for a 14,000 bit random access memory (RAM) to take the place of the Williams tube of the original proposal of Brooks, and
- a 76,000 bit "flying spot" cathode ray tube/photographic-plate store (Fig. 3) for read only memory (ROM) to store the line and trunk translation tables.

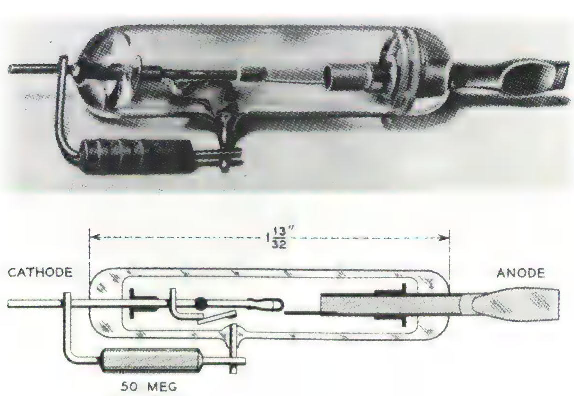

Fig. 1. The cold-cathode gas tube (a diode), which was the crossspoint element of the Morris switching network

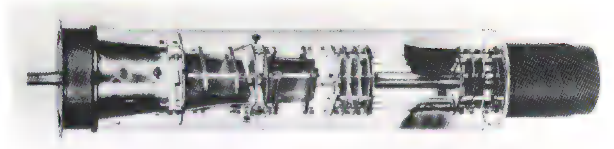

Fig. 2. A "Barrier Grid" tube, the device providing the Random Access Memory (RAM) of the Morris ECO.

The barrier grid store consists of three principal parts:

- the electron gun which electrostatically focuses and deflects a beam of electrons,
- the target, essentially a dielectric mica sheet upon which charge may be electrostatically deposited at each beam position, and
- the collector, located in front of the target.

Storage of information is accomplished by deposition of electrostatic charge on the mica (back plate of the tube) by the electron beam. The retained charge is the information "memory" of the tube. Subsequent positioning of the beam to a spot permits extraction of information in a charge-removal cycle.

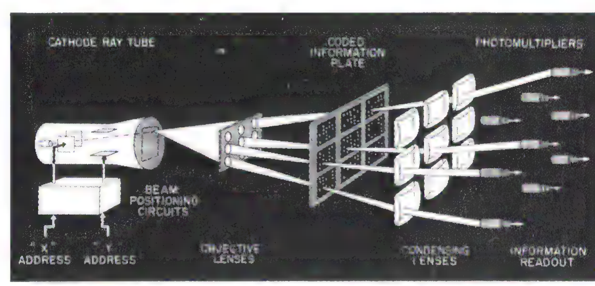

Fig. 3. The Morris Flying Spot Store: a simplified diagram.

A semipermanent memory of large capacity was required to store the line and trunk data and translation tables. To fulfill the goals of both security of information and ease of changing information content, the storage medium chosen was photographic emulsion, access to which was achieved by a cathode ray tube (CRT). The analogy of this method to the flying spot scanner of the television industry led to the device being called "a flying spot store".

The central control was to use transistor-diode logic [1] [5].

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[1] The original plan also included centralized teleprocessing of billing information at an "accounting center", but this was an ambitious project of its own and was therefore dropped early in the ECO development. It is interesting to note that this concept took until the early 1980s to become practical and placed into service.

2.2. The plan included the use of a single-stage gas-tube crosspoint concentrator that could be used within or remote from the central office. The distribution switching network in the central office used six stages of gas tubes with end-marking, a technique used with relay and gas-tube controlled crosspoints in the DIAD system (see Chapter II-3, sections 2.2 and 2.3).

Since it was not possible to send ringing current through the gas-tube network, it was decided that a system looking towards the future should also include a new electrical design of the telephone set. This set was known as the "low current set", operated on less than 15 milliamperes dc as contrasted with the well known sets that could require up to 100 milliamperes and 90 volts ac ringing. These telephone sets used tone ringers, much like some of the products on the market today. The tone was sent from the central office and could be passed through the gas-tube switching network.

The telephone set development proceeded in parallel with the ECO development. A trial of 300 of these sets was made in Crystal Lake, IL, in 1956 and 1957 [6]. While it was not appreciated at the time, the requirement of low current sets to work with a new switching system was an error in the overall economics for the rapid introduction of electronic switching offices.

2.3. As for the ECO development itself, two unexpected, but ultimately related, events took place within the first year of the development effort.

Firstly, a unique digital servo-control for the flying store scanner was invented by R.W. Ketchledge and R.E. Staehler. This greatly increased the speed and capacity of this subsystem.

Secondly, great design difficulty was encountered in carrying out the required call processing using the transistor-diode logic. (Today this concept is known as "wired program logic".) Necessity being the mother of invention, it was then that proposals by W. Keister (Fig. 4) and W.A. Budlong resulted in changing the central control to employ the then emerging *"store program" technique* with a general-purpose-logic central control unit. The resulting technique differed from computer programming because the switching programs have severe time limitations (generally related to "real time", that is, the 3600 seconds available within an hour, and scanning active lines at least every 10 milliseconds). Unlike most computer programs where speed relates to productivity, the speed of execution of call processing programs for a given number of call attempts must be carried out without noticeable delay.

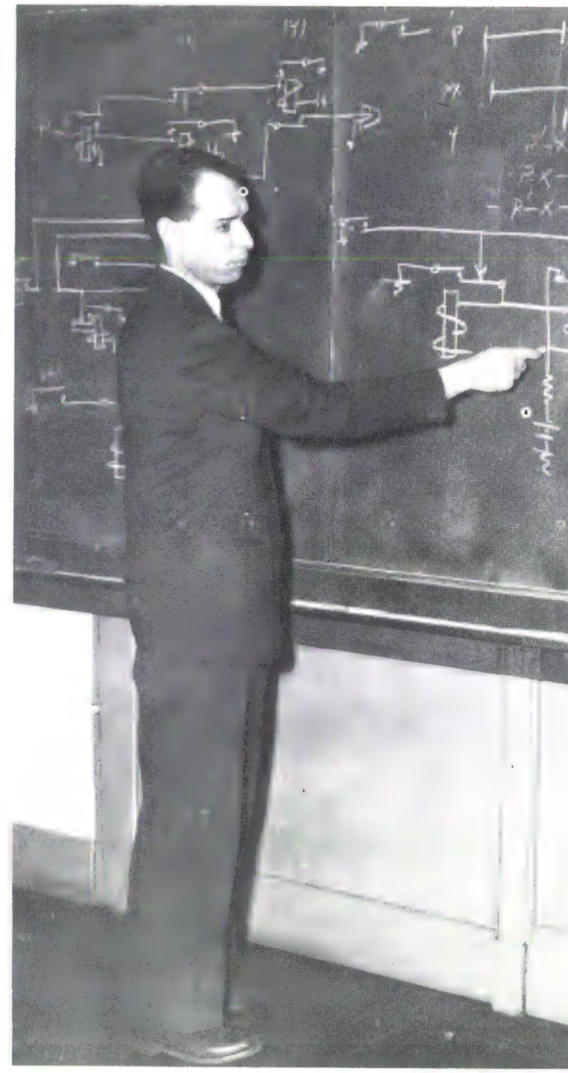

Fig. 4. W. Keister, the Father of Stored Programmed Control (SPC) in telephone switching.

Using the improved flying spot technique, which was now called the "flying spot store", it was possible to increase 30 fold its ROM capacity as well as to greatly improve its readout speed. The result was that the flying spot memory could be used to store not only translations but also the call processing and other programs. At that time it was expected that this program would use only 50,000 25-bit words.

2.4. The first installation of the experimental ECO equipment, called "Pre-Morris", was designed and built at Bell Laboratories in Whippany, New Jersey. Engineers from Western Electric, the company charged with producing the ECO, were assigned to work side by side with Bell Labs engineers from the early days of this project. This was necessary since it was early recognized that the success of this project was critically dependent upon the manufacturing costs.

The working prototypes of the basic system elements or subsystems were designed by different groups at Whippany. These elements were the gas-tube switching network, the Barrier Grid temporary memory, the Flying Spot store program memory. While each of these subsystems was being designed and made operable in separate laboratories, the programmers were writing the software to be used in the pre-Morris system. Box A describes what happened the first day in 1958 when the individually designed subsystems were assembled and wired together in a system laboratory and readied for the first system test.

With so many different technology disciplines of hardware and software being used in the Morris project, it was decided in 1959 that Morris central office would be considered a trial and not the prototype for the system that was to be placed into production. However, this did not detract from the enthusiasm of seeing the Morris office cutover successfully.

The ECO Morris central office was put into general service in November 1960. Box B describes what was "Morris" and what it did accomplish, being the first SPC system in the world. Box C emphasizes – if it is still necessary – what the fundamentals of the SPC philosophy are in telephone switching.

Box A

The first telephone call to have been completed under stored program control

For the previous twenty years Bell Laboratories had an installation in Whippany, New Jersey, a Northern New Jersey community about 30 miles west of New York. It was the birthplace of many radio and radar products. In May of 1954 under the direction of Clarence A. Lovell, a group of some 50 young engineers were brought to this location to start the initial design of the world's first electronic switching system to be placed into production. By March 1958 they had not only designed, built and tested the subsystems of this major switching undertaking, but they had, for the first time, applied the principles of stored program control to switching. One model of each subsystem was brought together in a system laboratory.

Howard N. Seckler was in charge of the group responsible for setting up this laboratory and for the testing of the system as a whole. He and his group had made extensive written lists of the tests to be performed and the steps to be taken that would ultimately result in a complete test of the system by the placing of calls and performing other checks.

On a gray cold day in March 1958, the individual subsystems had been wired together. Seckler, his group and supervision gathered to see the first steps taken in checking the interworking of the subsystems. Instead of proceeding with the meticulously prepared list of tests, Seckler stepped up in front of the gathering and 'throwing all caution to the wind' proclaimed – "LET'S SEE IF A CALL WILL GO THROUGH. DIAL! DIAL!". After carefully dialing the number for an intra offfice call, the called telephone at the other end of the laboratory rang. Thus, the first call ever to be completed under store program control became history.

Box B

What was Morris and what did it accomplish?

The trial of the first Bell System switching system took place in the small farmtown of Morris, Illinois, 100 km southwest of Chicago. This town was also well known at the time for being the site of one of the first, if not the first, nuclear power station in the United States, a station under construction at the same time as the radically new switching system.

The first public announcement of the location of installation of the ECO (Electronic Central Office) system was made in 1955. A headline in the local newspaper on Dec. 22, 1955 proclaimed " Morris to Have First Bell Electronic Phones in World".

The Morris office was the first central office using only electronics to provide commercial service. This included not only the central office but the telephone sets as well.

In 1960, the concept of Stored Program Control (see Box C) was a complete innovation in the design of telephone offices. It was such a radical departure that experts in electromechanical switching and electronic hardware design were disinclined to accept its principle since it departed so much from their experience and understanding, particularly the idea of writing a list of instructions by which the system would serve all calls and maintenance actions required for the operation of the office.

The Morris system proposal was greatly publicized at two Symposia held in February and March of 1957 when the design of the pre-Morris system was well underway. (The first meeting was attended by Bell System personnel and the second by representatives of Western Electric licensees from around the world (see Chapter VI-2). By the time of these symposia the principle of stored program control was perfectly clear in the minds of the designers of the ECO. In a paper presented by W. Keister, entitled "Control by a Stored Program" the three magic words were explicitly given:

"It is a method of control which places most of the control logic in a permanent memory as a stored program. The common control (thus) becomes a general purpose unit which is programmed to provide the features, options, and traffic patterns for a particular telephone office.... It requires a permanent memory of large capacity, with random access, and high speed."

By the time of the Morris cutover in June 1960 several technical compendia had been issued by the Bell System [1, 2]. A technical presentation of Morris was made to an AIEE meeting on October 12, with a distribution of a compendium of papers detailing the project [3].

While the Morris office was in operation from June 15, 1960, (when the first 30 lines were given service through the system) to January 24, 1962, the greatest day in Morris' short history was November 17, 1960 when dedication ceremonies were held. Not since the great train excursions to the first Strowger step-by-step central office location in LaPorte, Indiana, (a similar farmland town less than 100 km from Chicago) on November 3, 1892, had there been, or has there been as celebrated an event in telephone switching. The headline in the Morris paper on November 2, said it: "All eyes of the Telephone industry to be on Morris Nov. 17. Will dedicate first Electronic Central Office". At the ceremonies, the President of Bell Labs, Dr. James B. Fisk stated that the cost of the Morris project to date had been $25 million and utilized 750 man-years of efforts.

The Morris office contained 12,000 transistors, 105,000 semiconductor diodes, 23,000 miniature neon gas tubes (the crosspoints), two cathode ray tubes, 136 photomultiplier tubes, and two barrier grid tubes. The maximum lines served were 604, each with one (or more) low current telephone sets.

The art of designing electromechanical switching had reached the point where the designers and their managers had perfected the art of predicting the time and cost of new technical advances. Experience has proved to be even a more important factor in predicting the success in the development of electronic switching systems. When the Morris development started, it was expected to be completed and in service and production in three years. It took six years ...

Box B (continued)

There was an important factor in the success of the Morris project. It went into service without a backup. Most of the early electronic switching projects were predicated upon having a standby electromechanical switching system which could be brought back into service, should the new technology system fail in service. Those associated with the Morris development had the courage of their convictions. They used to point to this as a hidden reason for their success, which they never doubted.

The Morris system not only accomplished the first commercial public telephone service with an all electronic switching system using stored program control, but there were other important items to note. The system proved that large numbers of new electronic devices could be assembled and operated reliably. It also demonstrated the feasibility and forecast public acceptance of some of the new services that the low cost memory and the flexibility of SPC made practicable. These services included call transfer, add-on conference, abbreviated dialing, code calling of extension telephones, series completion of calls to non-consecutive line numbers.

Box C

What is SPC?
(a Box for the layperson)

Every switching office must include some means for interpreting and acting upon the signals incoming from lines, trunks and other inputs. The logic that accomplishes these functions as well as others required to process information held within the system, such as in data bases, is known as the "control". Data bases include information for translating directory numbers and parameters that indicate the constituent elements of a particular office.

Several varieties of controls have been developed over the years of electromechanical switching. Terms such as "direct", "indirect", and "common" control were established more or less as principles. In particular, for larger offices such as those serving several thousand lines, a plurality of common controls were generally required when using electromechanical technology [7]. These might be divided into groups by functions such as for originating and terminating traffic, or by traffic with each of a plurality of controls serving an equal portion of the offered call attempts.

Electronics has added new dimensions to these principles. First, of course, was the desire for the common control designed to use electronic technology to eliminate the need for a plurality of controls. In 1984, central control was still the most popular and successful form of electronic control.

But another dimension of electronic control is the way in which its logic is organized. For some systems with simple requirements, the logic may be wired as when using relays in electromechanical systems. Some have called this a "wired program" [8].

The most sophisticated form of electronic control has become known as *"stored program control" or SPC*. Here the control logic is general purpose. Indeed, it could be a processor or microprocessor designed for a use in a general purpose computer. SPC is characterized principally by a set of instructions or orders that may be performed by the processor and directed to control the peripherals including random access memories. Orders are stored in the random access memories, that are usually memories that cannot be lost by repeated reading or loss of power. (Most popular are Erasable Progammable Read Only Memories (EPROMs)).

Call processing takes place by the sequence in which the orders are read from memory. In SPC systems these sequences are called "programs".

Box C (continued)

The sequence may be interrupted by a decision point where a transfer in the orderly progression takes place. Generally SPC controls include an "executive" (scheduling, or operating) program that controls the overall sequence of functions that are implemented [9]. SPC systems have the advantage that the controls may generally be designed independent of the other subsystems. The system is modular. Each part of the system may be defined rather generally so it may be changed without changing other parts of the system. Several systems have evolved with new processors having greater capacity and replacing earlier designs [10].

The writer (AEJ) has defined a classification of central control systems (*) and distinguishes among them the class of SPC systems that are "fully SPC" [11]. This means that all decisions are made under program control. Some SPC systems allocate some known repetitive functions to be carried out by hardware or autonomous SPC that cannot be changed by the program in the central SPC. With the trend to distributed control, there may be many SPC subsystems in the same system (see Chapter IX-2)..

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* In this classification another type of control system is a design with specific logic circuits to meet a system architecture involving a switching network the elements of which are to be actuated by relays, for instance through markers. This class of control systems, in an elaborate switching terminology, has been designated by the author under the name of "action translators" [11]. Here a random access memory contains tables that provide the sequences that are needed for call processing. Decisions are made in the control logic, based on information received from peripheral portions of the system. These decisions drive the memory to different tables that apply to this particular call variation. In "action translators" systems the central control logic is designed for only a particular architecture of the peripherals.

2.5. By 1959, after the design and installation of the Morris Electronic Central Office (ECO) were well on their way, it was possible to make more realistic studies of the economics of the technologies employed. The results of these studies indicated that the Morris design, while proving the feasibility of many important new techniques, could not be deployed economically on a large scale and complet with the then popular crossbar technology. One of the principal elements of high cost was that of requiring the replacement of all telephone sets. This meant not only the regular well-known sets, but all varieties of sets in the entire telephone plant served by the office. It also meant that PBX trunk circuits and key systems would require new designs and the cost of their replacement had to be considered.

For these reasons, the ECO design team started to search for ways to avoid ringing through the gas-tube switching network. The most general solutions involved adding access relays to each line to permit the application of ringing at the line terminals. (This is similar to the techniques now being required for analog lines interfacing with local time-division digital switches (see Chapter VI-3).

2.6. At the same time effort had been proceeding in an attempt to find a switching network design using semi-conductor devices in place of what promised to be the more expensive gas tubes. While several technically interesting devices and network designs were proposed, none seemed to offer, for the foreseeable future, an economically viable solution.

As so frequently happens when technical progress is made, a most significant invention was made that changed the direction of the entire electronic switching project. This invention combined the use of well-known glass sealed contacts with an external electromagnet circuit. A short electronically produced pulse of the external electromagnet would magnetically latch the operated contacts until a short pulse in the opposite direction would open the contacts. This device was the invention of A. Feiner, C.A. Lovell, T.

Lowry and P.G. Ridinger of Bell Laboratories, four engineers who had been working on the Morris project. The device was almost immediately called *the "ferreed" relay* [12].

With this invention, electronic switching was freed of the need of changes in the telephone set technology. It was not until the era of new services, extending beyond the telephone, that changing the telephones would become more economically attractive (see Chapter X-2).

3. Other research approaches in the Bell Laboratories

During all this period, many other experimental researches, studies and projects on electronic switching were also considered in the Bell Laboratories.

3.1. One example of these projects was the *Remote Line Concentrator*. A line concentrator is a switching unit located away in a local network, close to a group of subscribers. This unit enables the traffic between the local central office and this group of subscribers to be carried out by a small number of lines and consequently reduces the copper requirements of the outside plant.

The Remote Line Concentrator studied by the Bell Laboratories was the first equipment to use junction transistors. Three models were built and placed in service in 1954. But, at that point in time, electronically controlled remote switching vehicles were not sufficiently economic and reliable to compete with electromechanical techniques.

3.2. The time-division centralized PBX Project of Bell Laboratories

About the same time that the ECO project was getting underway in 1954, the PBX system planners noted the future need for systems with more services and features. Their thought was to have a centralized control in a local office to control a number of remote units that would serve as PBXs. The central unit could be designed to provide the more advanced services, a point that grew in importance once the ECO project proceeded with SPC. Initially this exploratory development was known as the electronic PBX, or EPBX (see Chapter V-1). After several starts and stops, the project restarted in earnest in 1958.

Besides the need to explore the new electronic technology for PBXs, the Bell Laboratories management also wanted to hedge their large investment in the Morris project. With two development teams working, there was a bit of competition to find the more viable technologies and techniques. Particularly for this reason, time-division was chosen for the EPBX project. It was generally appreciated that analog time-division techniques were applicable to only limited size switching networks (see discussion of the British Highgate Wood model office, in Chapter II-5, section 3.2). For this and other reasons the EPBX project, proceeded using time-division switching.

The system consisted of analog (pulse amplitude modulation) time-division switching in the remote units and a centralized stored program control serving a maximum of 32 remote units. The SPC technology was similar to the one in No. 1 ESS (see Chapter V-1).

This PBX concept was the forerunner of the developement of the Bell System No. 101 ESS which was the first time-division switching system to use stored program control and to be placed into large scale production.

3.3. The ESSEX project

It was an exciting time at Bell Laboratories during this period. Not only were these switching projects much in evidence, but there were breakthroughs in electronic devices, military guidance and defense systems, nationwide dialing, microwave transmission, satellite and data communication. Switching research turned from space-division central control systems to digital communications. The project known as "ESSEX" (Experimental Solid State EXchange) was started in 1956 [13]. ESSEX was a laboratory model introduced to demonstrate the concept of what was called then "time separation switching"

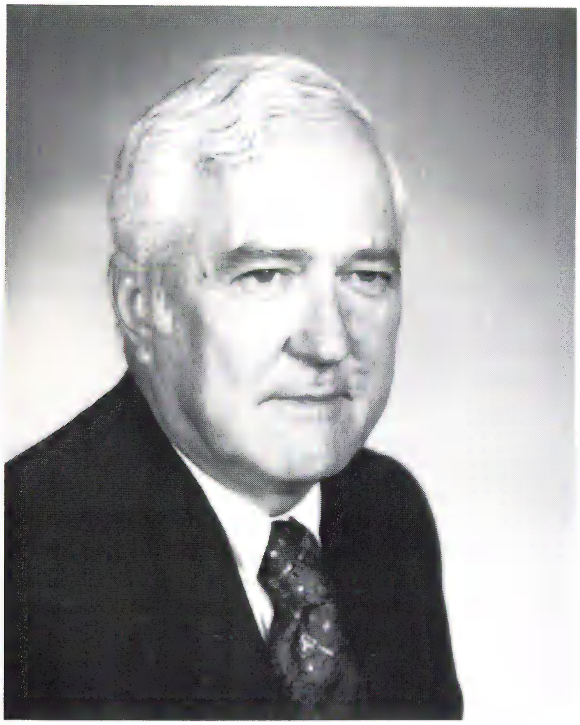

Fig. 5. H.E. Vaughan

(now time-division switching). It combined several innovative features:

- remote line concentrators (employing PAM technology), connected through PCM links to the local central office, and converting the analog speech samples to the digital form;
- time-division switching in the local central office;
- the use of solid state components (of the 1954–1959 vintage),

and it was primarily a digital system.

This project, lead by H.E. Vaughan (Fig. 5), had as its objective the use of digital transmission, which was then under exploratory development at Bell Labs. It was recognized early that to find a solution for interfacing digital transmission with switching would require a new approach. The result was a proposal for central switching using time-division digital rather than space-division techniques. This system experiment, which had such a profound affect on the "digital revolution", is described in Section 3 of Chapter VIII-3.

The concepts introduced in the design of the ESSEX were far in advance of their time and development of the system was not pursued. However the technical feasibility of the concepts had been demonstrated and ESSEX was a source of inspiration for many switching investigators.

We shall also have to note in the title of the article on ESSEX by H.E. Vaughan [14] what is perhaps in the technical literature the first appearance of the now so-widely spread expression "Integrated Communication".

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CHAPTER II-5

EXPERIMENTAL MODELS AND TRIALS OUTSIDE OF BELL LABORATORIES DURING THE 1955–1960 PERIOD

While the ECO and time-division field trials were being planned in the 1950s in Bell Laboratories there were other areas being subject to extensive experimentation in countries outside the United States.

1. Japanese researches.
A new type of component: the parametron

1.1. From 1954 to 1960 the Japanese carried out research on wired logic electronic systems using in the control unit a new type of component, the "parametron".

The parametron was an extremely ingenious device invented by Ei-ichi Goto at the University of Tokyo in 1954. Made up only of resistors, capacitors and inductance coils, it offered two bi-stable states and was therefore ideal for computer logic designs [1]. A parametron computer, the M-I (Musashino I), was completed in 1957 in the Electrical Communication Laboratory of the NTT, followed by other parametron computers (PC-I, PC-II at Tokyo University, and M-II) [1].

With the cooperation of E. Goto, Z. Kiyasu in the NTT Laboratories and S. Ooshima in the KDD Laboratories carried out research on the use of parametrons for the control of an exchange. Five switching systems referred to by the Greek letters "alpha", "beta", "gamma", "omega" and "tau" were successively tried.

1.2. The first, as early as 1954, was very short-lived. The second, "beta" (a prototype for small exchanges for which great demands were expected), and the third, "gamma" (a study prototype for large exchanges), were experiments in space-division type with crossbar switches in the switching network. The fourth, "omega", was also an experiment in space-division type but with semiconductors (combinations of PNP and NPN transistors) as crosspoints for the switching network. The semiconductor switch system was researched by S. Yoshida and K. Goto in the NTT Laboratories on both theoretical and experimental bases.

1.3. The fifth and last of the systems, known as "tau", on which research began in 1959, was an experiment in time-division switching based on the concept of 4-wire PAM technology which had been researched at the University of Tokyo by T. Osatake in 1958. Meanwhile the NTT Laboratories, OKI Ltd. and Fujitsu Ltd. made experimental models of 2-wire PAM switching systems. K. Habara of the NTT Laboratories introduced the idea of parametric amplifier in the resonant transfer concept, which made the intra-office transmission loss approach to 0 dB.

1.4. But the wheel of technology never stops turning, and rapidly:
– the parametron was unlucky enough to be

[1] In the United States, J. von Neumann also proposed, independently and about at the same time, the use of basically the same concept for computer design, but his proposal was not put to practical use in his country. [1, p. 137]

completely supplanted as a component by semiconductor transistors;
- by 1960, NTT had realized the advantages of stored program control compared with wired logic systems.

The result was a complete shift in the direction of Japanese research to produce a new generation of equipment to replace the NTT crossbar systems.

1.5. As for Japanese telecommunication manufacturers' achievements, several wired-logic electronic-control switching systems were brought into service about 1960 to provide business services. Main switching systems of this type, all of them experimental, were:
- NS-1B (in service in 1960 with 200 lines), NS-2A and NS-3A by NEC [2], and HITEX-3SD (in service in 1960) by Hitachi, all of them of the space-division type with crossbar switches,
- ACT-1108 by Oki (in service in 1964), FEAX-302A by Fujitsu (in service in 1961), and HITEX-3TD by Hitachi (in service in 1961) [3], all of them in time-division switching based on 4-wire PAM technology.

2. Models with a switching network made up of electronic components

2.1. To many, electronic switching meant a system with a switching network made up as an array of electronic components, i.e. by using semi-conductor devices as crosspoints in the switching network. We give here only a summary of the various experimental trials on this line of research, which took place during the period covered in this Chapter.

Philips, in the Netherlands, had invented in 1956 a new type of transistor component, the "PNPN" component. An arrangement of two junction transistors in a "hook connection" (see Fig. 1), which is a single four-layer device, the PNPN yields a bistable switch that can be end-marked like a gas tube and is acting as a diode. The PNPN element acquired great success in its time and many papers on its use as a crosspoint

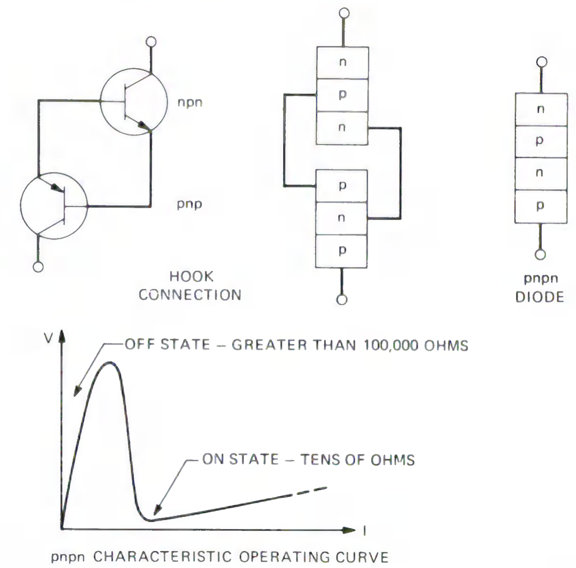

Fig. 1. The PNPN diode, a solid state alternative for crosspoints in the switching network of an exchange:
- top left, the "hook" configuration of transistors
- top right, the PNPN diode
- below, on-off characteristic curve of the PNPN diode

element were still presented at the Paris ISS 1966.

Philips started experiments for the use of PNPNs in the switching network of an exchange. They build up first a laboratory model (the ETS1 system) [4]. Later this experiment was field tested as the ETS3 system in Utrecht (Netherlands) and Aarhus (Denmark) from 1967 to 1972. To cope with the fact that these crosspoints could handle only low current signals, new low-current telephone sets were used in these field trials, with the customers being asked to change sets on a given date.

The PNPN elements were also used in several other countries:
- in Japan, Hitachi built two experimental systems (HITEX-1 and -2, both in service in 1960) using PNPN crosspoints.
- For the French navy, LCT (of the ITT group) in France developed a small fully electronic space-division switchboard (20 lines) using silicon-junction diodes as crosspoints [5]. The semiconductor elements available at that time

precluded the feasability of an industrial application.

- The research Department of Televerket, the Swedish Administration, in cooperation with LM Ericsson, experimented with a system called "TEST1" also using PNPN crosspoints. A 100-line model was built. Its memories used perforated metal cards for exchange data memory, magnetic cores for RAM and a magnetic drum for number translation. The model is described in [6].

(In the early 1960's all the latter companies jumped from the PNPN crosspoint to PCM time-division systems.)

The PNPN element as a switching network crosspoint was also considered attentively at the Bell Laboratories before they preferred for their future ESS 1 to adopt their newly invented device, the "ferreed" (see Chapter II-4 under 2.6).

We can also note that, as we have seen in 1.2, the Japanese "gamma" parametron exchange model developed in the NTT Laboratories used semiconductor components as crosspoints elements in its switching network.

2.2. Gas-tube space-division switching was another line of research, but it was essentially confined to the United States ECO system (as we have seen in Chapter II-4) and the West German Siemens' KAMA system. The KAMA system will be described in Chapter V-7 retracing the long course of action which led to the gradual transition of Germany's electromechanical technology towards electronic switching.

3. Time-division switching with pulse amplitude modulation (PAM) samples

3.1. In the wake of the inventions of Deloraine and Ransom described in Chapter II-3, section 3, the mid-1950s was an active period of study and experimental trials based on the principles of the new concept of time-division switching. The concept was an attractive one. The computer industry, or even more the universities then leading the research on computer development, (see Chapter III-3), were offering new devices for memories, an essential component to build up prototypes in time-division switching.

In several countries, laboratories of the most important switching equipment manufacturers and also leading research institutes in universities were engaged in this type of research. Their list is a long one:

- Australia, France (LCT), Germany (FRG) (Siemens, see below), Japan (University of Tokyo, NTT, Fujitsu, Hitachi, Oki, see 1. above), Sweden (LM Ericsson, see below), the United Kingdom (GPO – see below – and STC), the United States (Bell Laboratories as we have seen above, Automatic Electric, Stromberg Carlson), the USSR (EATC 20) and Yugoslavia (Institute for Automation).

There was great commonality in all the studies then being carried out:

- time-division switching of this period was based on pulse amplitude modulation (PAM) samples, with speech current sampling at 10 (or 8) kHz;
- a common 100 (or 125) microsecond time interval (a "time slot") was assigned to both the caller and the called party by the synchronous opening into a common bus (or "highway" in the British terminology) of electronic gates consisting of diodes. The opening of the gates was controlled by a memory which contained the addresses of both parties;
- the now classical scanning principle was used to identify the calling line.

In the following sections we describe the four most important realizations in this type of time-division switching that took place outside the United States or their Bell Laboratories.

3.2. British research: the Highgate Wood exchange

3.2.1. By the early 1950s the United Kingdom was Europe's leader in research on the use of electronics in telecommunications, not only in transmission which until then had been the only aspect involving the use of electronic devices, but also in switching, a field that had traditionally been hostile to the very idea of incorporating electronics.

Box A

Fig. 2. T.H. Flowers

The personality of T.H. Flowers

In the United Kingdom, the foremost research worker in electronic switching was Thomas H. Flowers, of the Dollis Hill Research Centre of the General Post Office (GPO). Flowers was a well known figure in international circles as Head of the United Kingdom delegation at many international meetings and even more for his research and his many articles, first on voice-frequency signaling in the 1930s [7] and later, in the 1950s, on electronic telephone exchanges [8], and also as an author of a book on switching [9].

From 1935, T.H. Flowers, then a young engineer at Dollis Hill, began to explore the use of electronics in telephone exchanges. "By 1939, I felt able to prove what up to then I could only suspect: that an an electronic equivalent could be made of any electromechanical switching machine... I reached the point that meant that not just parts of a telephone exchange could be electronics – complete exchanges could. I knew nothing of similar ideas being pursued elsewhere because none had reached the stage of publication" [9].

In 1942, T.H. Flowers together with S.E. Broadhurst and W.W. Chandler, two of his Dollis Hill colleagues, was commissioned to take part in top-secret work at Bletchey Park, a high-security establishment about 50 miles north of London. There, cryptanalysts, including A.M. Turing as the leading mathematician, were deciphering or trying to decipher German military messages encoded on a machine called ENIGMA. For this work, an electronic machine called COLOSSUS was to be built with the design expertise of the three Dollis Hill engineers under the leadership of Flowers. "Many of the concepts later used for digital computers were incorporated by them in the Colossus equipment" [10]. Owing to British security restrictions, information on the Colossus cryptanalytic machine was declassified only a few years ago. Few people in the computing community had ever heard of Colossus before the publication of the first articles on it in issues of the Annals of the History of Computing [10]. Several historical books, with a larger public audience and, for some of them, nearly bestsellers, have then been published on Colossus and its influence during the last years of the war.

Returning to Dollis Hill after his war activities (which remained completely unknown to his countless international collleagues throughout his active career at the GPO *), Flowers became a promoter, or rather the promoter, of time-division switching in his own country.

Flowers' expertise greatly influenced the UK Post Office in its procurement of switching equipment. Unlike the case of other European countries, a crossbar system was not developed in the United Kingdom at least until 1971 and then only on a limited production scale. For more than 25 years after the war, only one switching system, the Strowger step-by-step system, was manufactured in the UK as the British GPO standard system. Great hopes – too great hopes – had been placed in Britain on the success of electronic switching and its advent for in-service operations in the not too distant future. Such hopes were certainly only one of the determining factors which framed the GPO strategy for the development of its national network and switching equipment.

* T.H. Flowers ended his career as Head of Switching Research, British Post Office.

3.2.2. Research into electronic switching began very soon after the Second World War at the General Post Office (GPO's) Dollis Hill research station and in the laboratories of the British switching equipment manufacturers. The research, directed by T.H. Flowers at Dollis Hill, concentrated from the beginning on time-division electronic switching, then known as "time sharing". It benefited from the experience not only of Flowers himself but also that of a number of his colleagues at Dollis Hill who had been engaged with him in the COLOSSUS wartime project (see Box A), a machine considered the world's first electronic calculator ever put into service [2], according to some technological historians.

3.2.3. The JERC (Joint Electronic Research Committee)

An agreement was signed in 1956 whereby the GPO and the following five British switching equipment manufacturers joined forces to found the Joint Electronic Research Committee (JERC):

- Associated Electrical Industries Ltd. (AEI), which appeared at the time of signature under the name of Siemens Edison Swann Ltd.;
- Automatic Telephone & Electric Co. Ltd. (ATE);
- Ericsson Telephones Ltd.;
- The General Electric Co. Ltd (GEC);
- Standard Telephone and Cables Ltd. (STC).

The JERC started by making a preliminary evaluation of the different possibilities open for designing an electronic system. The choice was not simply between space-division and time-division switching: consideration was also given at the time to frequency-division switching, a mode which engineers have now completely discarded but which is worth a mention here, if only for the record.

3.2.4. Pulse Amplitude Modulation time-division switching at the Highgate Wood exchange [11]

The time-division switching system then to be proposed was not based on PCM systems, which still lay in the future, but had to operate on Pulse Amplitude Modulation (PAM).

At the Highgate Wood exchange, pulses at a 10 kHz frequency sampled the speech wave and, according to the PAM principle, their amplitude was equal to that of the speech current at the instant of sampling. Interspersed pulses corresponding to 100 speech channels, with each pulse occupying a time slot of 100 microseconds, were fed along transmission channels known as "highways".

These highways formed the system's switching network. Separate highways were used for inward and outward transmission, so that each line required a 4-wire/2-wire terminating set.

Each highway was connected to the lines via electronic gates where pulses were allowed to pass through at time intervals determined by the logic of a common control unit. The originating highways were connected through gates to terminating highways. Gates passed pulses from the calling line to the originating highway, between the originating and terminating highways, and from the terminating highway to the called line. The gates for lines to be interconnected were operated simultaneously in a "time slot". The time slot is a designation of the time interval fixed for the transfer from one highway to another, depending upon the availability of a time slot for this transfer.

Given the average traffic of subscriber lines, a pair of highways (one for each direction of transmission) could serve a group of 800 lines. An exchange could consist of a set of several such groups and their associated highways. The process that we are describing was fairly novel at the time [3], at least in Europe.

[2] In fact it was simply a highly specialized computing machine and thus a far cry from a data computer like the American ENIAC, which was the first of this type.

[3] However, this research did run more or less in parallel with the studies being carried out in Germany (FRG) at roughly the same time on a similar time-division switching system (the EVA system, see 3.3)

The architecture and design of the Highgate Wood system relied essentially on memories which controlled all time-slot assignments to individual highways, as well as transfers from one highway to another. The memories belonged to their own generation: given the time spent studying the prototype, they were based essentially on a technology developed a few years earlier in the laboratories of Britain's universities engaged in computer research (see Chapter III-3). The main memories consisted of magnetostriction delay lines and there were also magnetic drum devices acting as auxiliary memories (e.g. for directory number/equipment number translation and for recording the charges to the subscriber).

3.2.5. Design of the Highgate Wood exchange

The time-division system researched by the JERC was designed to offer after development a capacity of 20,000 subscriber lines. It was to provide all – but not more than – of the ordinary telephone service. It had to be capable of being readily incorporated into the existing network so as to interwork with Britain's Strowger exchanges and the signaling system they required. Continuity of operation was also an absolute priority and had led for the prototype Highgate Wood exchange to a whole series of design arrangements whereby essential exchange components, such as highways, were duplicated.

The details of the design were studied jointly by a team on which each of the associated organizations was represented. The developement and the manufacture of the different parts of the prototype were then assigned to the participating partners who were free to use those techniques and components in which they had more experience, or which they regarded as most appropriate. It had apparently been decided to obtain comparative data with a view to determining which of the different components and devices used were the best. Although intended for the best, this idea of "sub-contracting" the different components on a piecemeal basis was somewhat unfortunate and, for many of the partners, certainly led to the difficulties which the prototype exchange encountered from the outset.

Under the first phase of JERC research, a laboratory mock-up was installed at Dollis Hill in November 1959. This was followed by a 600-line exchange which was installed in the North London suburb of Highgate Wood. The Highgate Wood exchange was inaugurated at a solemn ceremony in December 1962. The public was told that its introduction, precisely 50 years after the first British automatic exchange had been installed at Epsom, marked the beginning of a new era. Despite the solemnity of the ceremony, those appointed to operate the exchange at the time of its inauguration still have somewhat bizarre memories of the affair...

Although the system was working, it was quickly realized that it was little more than an experimental model intended to operate only for a very short time. Time-division switching was consequently regarded in the United Kingdom as a still unripe technique which would have to await further developments for an indefinite period of time. Harris, who in [12] gives the background to the initial developments of electronic switching in the United Kingdom, stated in an article published in 1966 that, with the hindsights of the intervening four years, it had to be recognized that the programme which produced the Highgate Wood exchange was premature but had none the less led the United Kingdom to make a drastic reassessment of the very principles of telephone switching.

A detailed description of the Highgate Wood exchange is given in [13] by S.W. Broadhurst of the GPO Research Station (who, like Flowers, was a veteran of the wartime Colossus project).

The system had been initially designed in 1956 at a time when sufficiently reliable transistor components were still unavailable. Although transistors were fairly widely used in the Highgate Wood hardware, the large number of hot valves which had still to be used resulted in a difficult heat dissipation problem. The number of electronic components employed was considerable when viewed in the number (only 600) of subscriber lines: there were some 3000 electronic "valves", 150,000 diodes and 26,000 transistors, not to mention an impressive volume of resistors and capacitances, all in the form of discrete components.

In retrospect, therefore, the famous Highgate Wood exchange stood out as a *monstre sacré* and, in the history of electronic switching, is equivalent to what the ENIAC machine of 1945 stands for in the history of computers.

3.3. The EVA prototype of Siemens (Germany)

While still researching its ESK system (see Chapter V-7), a transition from electromechanical to electronic switching, Siemens was also pursuing a whole series of studies into two forms of electronic switching, namely time-division and space-division switching. The former gave rise to the entry into service in early 1962 of an experimental system known as EVA (Elektronische Vermittlung Anlage) [14, 15]. A 1000-line EVA prototype was put into service to serve the internal network of Munich, Siemens Laboratories. Its basic principles matched those described in section 3.1.

(The EVA prototype was also used by Siemens as test bench for push-button customer dialing and served for trials of 2-out-of-5 voice frequency code-signaling (see Chapter X-2) between customer stations and the exchange.)

Although the EVA installation operated satisfactorily for a long time, its trial assessment showed that the time was not yet ripe for introducing time-division switching. Indeed the results offered litle hope, at that time, of producing cost-competitive systems large enough to be installed in public exchanges.

3.4. The EMAX prototype model of LM Ericsson [16]

3.4.1. LM Ericsson had taken an interest in time-division switching at an early stage. Its first trial exchange model, the EMAX ((Electronic Multiplex Automatic Exchange) was already completed in 1954. EMAX was however only a laboratory mock-up, made up entirely of diodes and cold cathode tubes (see Fig. 4).

We can note that the choice in EMAX of the value of 8 kHz for the speech sampling rate (and of a corresponding 125 microseconds for the "time slot" switching element) was anticipating the standard PCM values which were to be adopted by both the ATT for its "T-" transmission system and, later, by the CCITT in its PCM Recommendations.

Fig. 3. G. Svala, inventor of the resonant transfer principle

3.4.2. The EMAX design used a new principle for the transmission of speech through a time-division exchange, the *resonant transfer principle*. Its inventors, G. Svala (Fig. 3) and B. Haard [17], showed how the transmission circuits through the exchange could be designed to be practically free from loss. Their invention opened the possibility of building the exchange without any insertion of amplifiers, and what is more, of using a single-wire speech network.

The resonant transfer principle uses the charging of capacitors *Ca* and *Cb* (see Fig. 5) inserted respectively on the lines of the two connected customers (calling party and called party) when they are connected to the speech bus during a common time slot of the system. With the chokes *Dra* and *Drb*, *Ca* and *Cb* form oscillating circuits so designed that the two capacitors exchange their charge. During the next contact opening, the speech energy stored by the capacitor of the

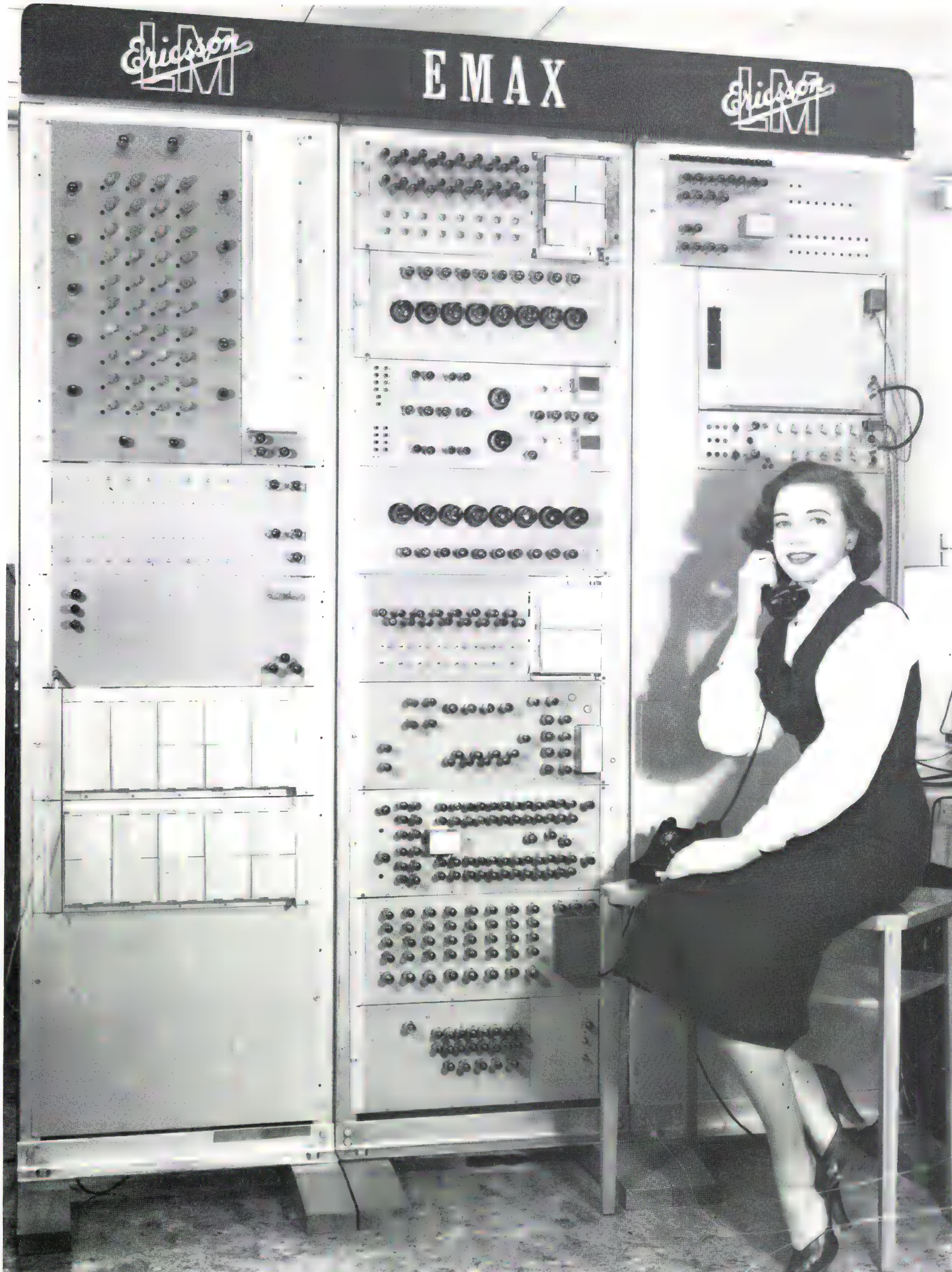

Fig. 4. The EMAX prototype model of PAM time-division switching (1954-1955)

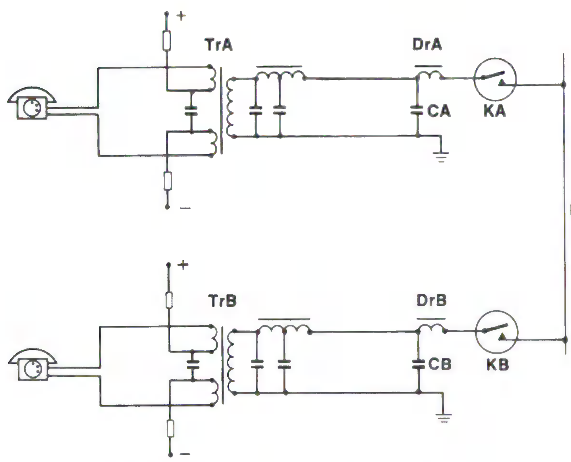

Fig. 5. The resonant transfer principle

customer line is transmitted through the low-pass filter of the line, and the speech is thus reformed with transmission practically free of loss [16, p. 137].

The concept of resonant transfer obtained a large success both at LM Ericsson and in many other places [18]. Its principle was, for instance, applied in the design of the Bell System ESS No. 101 of PBXs [19] and, as we have seen in 1.3, in the experimental "tau" parametron TDM system of Japan.

3.4.3. The conclusions drawn by the LM Ericsson management from the trial results of the EMAX prototype were similar to the ones obtained in the other countries researching on PAM time-division switching: electronic components (tubes and diodes) were expensive, they were not completely reliable and they consumed a large power.

3.5. Activities at Stromberg-Carlson

In the United States, the Stromberg-Carlson Co., then of Rochester, NY, designed several time-division PAM exchanges for mobiles, CDO (Community Dial Office) and PBX service [20]. These systems employed a form of transistor and diode logic known as Dynalogic [21]. The systems were called ECDO and EPBX respectively.

As a separate central office system the ECDO could not compete with other systems then being brought onto the market. However, the technology was successfully introduced into a register-sender system [22] for electromechanical direct control central office systems, such as step-by-step and XY systems [4]) and for a military electronic switching system application.

3.6. None of the PAM time-division systems in these trials were commercially successful as exchanges in the public network, mainly due to intelligible crosstalk inherent in the systems. As a result time-division was abandoned for public exchanges until the mid-1970s when the first generation of exchanges designed to switch PCM samples of speech were introduced. However, the PAM technique continued to be largely used in time-division PABXs manufactured until the late 1970s.

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Part III

Birth and early beginnings
of the computer developments
their impact
on electronic switching developments

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CHAPTER III-1

IN THE HISTORY OF MANKIND, THE FASCINATING LONG MARCH UNTIL THE 1930s TO DEVELOP COMPUTING DEVICES

1. The birth of the electronic computer industry – a major event in the history of technology

Few topics in the history of technological development are of such broad appeal as the origins of the computer industry. There are several reasons for that:
- the ever-growing numbers of engineers in this dynamically expanding sector,
- beyond that relatively restricted circle of engineers, the vast number of computer users, the legions of financial analysts and masses of journalists in search of a good story ...

Few topics today may be more attractive to the historian [1]:
- its "prehistoric" period dates from only 40 or 50 years ago;
- the wealth of documentation with the only problem being to choose the best source material;
- most of those who played an important part in the early development of this sector are still alive and are ready and willing to tell their story.

And, last but not least, an account of the origins and early stages of the "computer industry" is eventful and fascinating to readers of such a history.

2. A model history – technologically

2.1. Unlike the history of the automatic telephone switchgear, which has not been the subject of many serious researches, there is no lack of literature concerning the origins of the computer

[1] When reviewing the successive stages of this history which covers little more than 40 years, even the amateur historian must be struck by the many analogies with the accepted history of the development of our western civilization. The main steps in the development of the computer industry are similar to those which, between 1000 A.D. and the 17th century, were marked in Western Europe by the change from the period of lordlings to that of feudalism and of the barons; and later to the rise of kingdoms and empires, the precursors of the States of today. When following the parallel development of these two histories, we can for instance note that, in the computer industry as in the case of the growth of the Austrian Empire or other European monarchies, competition and conflict between rivals were often settled by marriage. Some of the established links between computer companies worked out well, sometimes giving birth to a second generation, with a proliferation of subsidiaries throughout the world. There were also, of course, less successful unions, ending in some savage divorce proceedings after only a few years.

For the uninitiated, it is as difficult to ascertain which computer manufacturing company produced a specific machine as defined by an acronym and serial number, what were the origins of this or that company, or what are its financial or technical links with other companies, as it is to learn which territories belonged to which noble household of Western Europe in a particular century, or to unravel the genealogies of ruling families.

We shall not enter into all these detailed complexities and only provide the reader with some basic points of reference.

industry [2]. Many books are devoted to this subject. Historical articles have become regular features in computer journals and technical literature (e.g. Datamation). Since 1979 a specialized periodical, "Annals of the History of Computing" (abbreviated hereafter as "AHC"), is published with a large audience.

But let the reader relax !.. The present Part III of the book in no way seeks to retell a story which has already been related by more eminent experts: its purpose is merely to provide a concise account of the successive stages of the evolution of computers and to draw attention to the mutual effects which that evolution and the development of telecommunications (and in particular the development of telephone switchgear) have had on each other.

2.2. The account given here of early developments in computers may be of special value when pointing at the circumstances prevailing at the birth of what has since become not only a major industry but also a dynamic force in modern civilization development [3].

Readers may observe how striking are the similarities between the first – and very hesitating – steps of those who, during the period 1940 to 1955, broke new ground by developing computers, and the earlier steps of:

- Strowger and his American rivals who, 50 years previously, in the 1890s, produced the first automatic telephone exchanges; and
- the youthful pioneers, in Silicon Valley, California, who 80 years later, in the 1970s, developed microelectronics.

2.3. Scientific achievements, some of them centuries old, technical innovations made over ten or more years, simple inspiration – all of these were necessary but far from sufficient as prerequisites for the introduction of electronic computers.

The shock of World War II, with its overriding requirements of national defence, meant that – in an environment in which profitability was no longer the sole criterion – young research workers, keen on working in a stimulating and challenging field, were given the chance to develop their ideas, with considerable freedom of action and all the resources necessary at their disposal ... A well-subsidized academic environment ...: these were the conditions in the United States where, far from the fighting front, these eggs, so carefully incubated, were hatched.

The research work undertaken during World War II did not, however, bear fruit until after the end of the war.

2.4. During the same period, research outside the United States was merely confined to two European countries – the United Kingdom and Germany, each directly engaged in the war [4]:

- in the United Kingdom, development began with the mobilization of research workers in secret defense projects and cryptographic studies aimed at breaking enemy codes ("Colossus" project). A further stage – which did not commence until after the end of the war – was marked by research work in universities (see Chapter III-2).
- in Germany, in 1936, Konrad Zuse applied for a German patent for a mechanical computer operating on binary digits. During the

[2] A good illustration of the multiplicity of documentation on the origins of computers is provided by the bibliography which Brian Randell, Professor of Computing Science, University of Newcastle-upon-Tyne, published in 1979 on the subject. This bibliography [1] is particularly valuable by virtue of its detailed annotations even if it is limited to the history of computers up to their "coming of age", i.e. up to circa 1955. Although not exhaustive (as regards articles published in the socialist countries of Eastern Europe, and particularly in the U.S.S.R.), the bibliography includes no less than 800 entries.

[3] This account might perhaps provide useful guidance to those charged with the responsibility of national policies in the field of research. Also those responsible for university science departments could perhaps perceive from this account some first-rate tips for the successful operation of their projects in applied research.

[4] In a third country, France, research work started in 1939 at the Centre National de la Recherche Scientifique (CNRS), under L. Couffignal. He was since 1936 an advocate of the numbering system based on binary numerals and its application for the development of binary calculators. His work was interrupted by the German occupation of France in June 1940 and only resumed in 1947 at Institut Blaise Pascal.

war, his research on electronic computers received scant official support. At the end of hostilities, all but the last of the four Zuse computers (known as Z1, ..., Z4) had been destroyed in air raids and the achievements of Zuse remained virtually ignored by non-German computer specialists for several years.

3. Scientific successes in the field of computing in previous centuries [2]

3.1. No serious history of the computer can omit reference to those renowned mathematicians Pascal and Leibniz (Box A): it was they who, in addition to other achievements, made the earliest numerical computers.

Nearer to our time, the nineteenth-century research workers, now also universally acclaimed after many years of oblivion, Babbage (and his assistant, Lady Ada Lovelace) (Box B) and Boole must be mentioned.

The roll of famed mathematicians would be incomplete without reference to the much more recent worker Alan Turing (Box C). He has not yet received the universal recognition he deserves, but posterity will doubtless come to appreciate his outstanding qualities and realize how much his concepts have stimulated modern work.

3.2. Among other scientists worthy of mention, we shall quote only two names:
- Muhamed al-Khwarizmi (786–846 A.D.), an Arab mathematician who, in Tashkent (now, in Uzbekistan, USSR), first defined what is now called – after him – an "algorithm";
- G. Gauss (1777–1855) who amongst many other better-known achievements may be considered as one of the first champions of binary numbering.

Box A

Pascal and Leibniz

1642 – Blaise Pascal (France, 1623–1662) invented the first automatic computing machine which could add and subtract. The machine could also convert the value of various monetary units of the period (pounds, deniers and sols).

He designed the machine as an aid to bookkeeping and for use by his father, who was Finance Controller of the Kingdom of France for Normandy, in Rouen.

1671 and 1694 – Gottfried Wilhelm Leibniz (Germany, 1646–1716) made a computing machine which could perform the four basic arithmetical operations: addition, subtraction, multiplication, and division. The machine, a "stepped reckoner", was provided with means for the carry-over of a digit from one column to the next and was intended for astronomical computations.

4. The computing devices existing at the end of the nineteen thirties

4.1. Without going far back into history, mention must be made first of all to the mechanical refinements (including the rotating pegged cylinder) resulting from the great advances in watchmaking made during the period of the 17th to the 19th centuries. Watchmaking, the science of time, must receive at least a mention in this book and especially in this Volume II, which is largely devoted to digital switching. Switching, and a fortiori digital switching, based on discrete values of time and not on a continuum, should – as indeed should the computer industry as a whole – be recognized as the technological descendants of watchmaking [3]. If any doubts should occur regarding this ancestral link, no better symbol of its reality can be adduced than the masterclock which, in a digital exchange (or in a digital national network), controls all the sequences of operations to an accuracy of nearly one nanosecond.

4.2. The name of Jacquard must now be mentioned (Box D). He invented the device which, for more than 150 years, was the only one used for programming. Although science historians have pointed out that he had a number of precursors (see Note to Box D), it was clearly he

Box B

Babbage and Lady Ada

1822–1835: Charles Babbage (Great Britain, 1792–1871) developed an automatic computer to prepare mathematical tables (e.g. of trigonometric functions), the "difference engine", also called an "analytical engine" (1834).

Features of the machine included:
- the gear machinery of a number of adding machines (20-digit registers); and
- the receipt of instructions given by commands derived from the logical devices of the type used in the Jacquemard automata and in the Jacquard weaving looms.

The Babbage machine was already equipped with:
- a control unit;
- a "store" (a memory storing input data, intermediary results, and the output data before their transfer to the printer);
- what Babbage called a "mill", i.e. a logical and arithmetical unit with cards controlling the "repeating apparatus" of the "mill" (the sequential operations);
- an output unit consisting of a card perforator (Babbage also had the idea of a printing device and of a "curve-drawing" device, but these were not implemented); and
- in its system of logic, a "conditional transfer" operation which permitted the comparison of quantities and, depending on the result, a move to receive another instruction.

Two "difference engines" were build and operated:
- one in England used specially to compute actuarial (life expectancy tables; and
- one in Sweden, in 1855 by G. Scheutz, which was subsequently purchased by the Astronomical Observatory in Albany, New York, and which is at present in a United States museum.

1850–1852: Augusta Ada Byron, Lady Ada Lovelace (United Kingdom, 1816–1852), the only daughter of Lord Byron, the poet, was a lady mathematician who may be considered as the first "programmer" and who wrote the computation programs to control the sequential operations of the Babbage machine.

who brought into use the paper tape with punched holes as the tangible expression of a program – a program which he used on his loom to implement designs for silk brocades. Showered by the Emperor Napoleon the First with honors, Jacquard overcame a host of difficulties – strikes, broken looms, stormy meetings with weavers who feared that automation of their tasks would cost them their jobs – and lived to see his looms come into widespread use throughout the textile industry. The punched card or, more precisely, the belt made up of a sequence of such cards, originating on Jacquard's loom, became one of the basic tools of automated industry. A whole series of technological developments resulted from Jacquard's punched cards (or perforated belt):

i) the device used by Babbage when he converted the machinery in his "mill" to carry out a controlled program of successive operations;
ii) a variant of this technique – a narrow ribbon of paper continuously passing over a device which punched coded holes corresponding to the letters of the alphabet – became a typical feature of several developments in telegraphy from the middle of the 19th century onwards;
iii) Hollerith's numerical card, derived from that of Jacquard.

Box C

Alan M. Turing (United Kingdom, 1912–1954), mathematician and logician

At the age of 25, after studies in mathematical logic at Cambridge University (UK), he went to Princeton University in the U.S for a Ph.D., where he published in 1937 his famous paper "On Computable Numbers, with an Application to the Entscheidigungs Problem". He introduced as an abstract concept a description of a universal computer machine (the "Turing machine"). The machine passed from "internal states" to others according to the sequential instructions received from a programming tape, containing the algorithm embodying the mathematical solution of a problem. Turing demonstrated that, in mathematics, there are two classes of problems – i.e. those which can, and those which cannot, be solved by his machine in a non-infinite time. The first class is today described as "Turing computable" or, more concisely, "computable".

During World War II, Turing was engaged in the UK in cryptographic research for the "Colossus" project. In 1945, in London, he was one of the designers of the Automatic Computing Machine (ACE), and in 1949, at Manchester University, of the Manchester Digital Machine (MADM).

4.3. Hermann Hollerith (Box E) was the founder of the punched card machine industry. Originally designed to cope with the large mass of data to be processed in the compilation of periodic national censuses, punched card machines soon became essential tools in numerous accounting operations and for stock control in large commercial undertakings.

Inspired by the success of Hollerith's devices, other engineers followed in his footsteps and founded companies bearing their names – as in the case of James Powers in the United States around 1910 (Box F) (with mention of the British Powers Samas Company) and, somewhat later in Norway, in that of Frederik Bull, whose patents were first put to commercial use in Switzerland,

Box D

Jacquard

1805–1807: Joseph M. Jacquard (France, 1752–1834) is considered to have been the first to use a "programming system" based on the punched cards, in Lyon (France) for silk-weaving looms [see Note to this Box].

The punched cards (or a sequential band of cards) controlled the sequence of operations of the loom according to the pattern ("brocady") to be woven. Through the holes in the punched card, hooks pulled warp threads down, thus selecting the threads over which or under which the shuttle had to pass.

[Note to Box D – Mention should also be made of the following designers of "automatic" looms, whom Zemanek [4] considered to be the precursors of Jacquard and of his card-programmed loom:

- Broesel (Germany-Austria) around 1690;
- Falcon and Bouchon (France) around 1728;
- Vaucanson (France) in 1745; and
- Cartwright (Great Britain) around 1787.]

Box E

H. Hollerith

1890: Herman Hollerith (United States, 1860–1929), at the United States Bureau of the Census for the (decennial) census of 1890, had the idea of representing values by holes punched in a paper card and having these values "read" by electric sensors. Hollerith cards had 288 places where holes could be punched. Reading brushes, when encountering a hole in the card, gave an electrical signal to a tabulator. Sorting boxes were connected to the tabulator's counters.

In 1896, Hollerith left the US Census Administration and founded his own company, the Tabulating Machine Co. This company, after a merger in 1911 with two others, became the Computing Tabulating Recording Co. (CTR) which from 1914 was managed by Thomas J. Watson (United States, 1874 – 1956) and is the ancestor of the International Business Machines (IBM) company, the name of which dates from 1924.

Box F

J. Powers

For the preparation of the 1910 census, the United States Census Administration, no longer on good terms with H. Hollerith, decided to make its own mecanographic equipment. The engineer James Powers was put in charge of this operation. In 1911 he left the United States Administration and founded his own company, the Accounting and Tabulating Machine Co. [see Note to this Box] which was absorbed in 1927 by the Remington Rand Co. – which, in turn, merged in 1955 with the Sperry Gyroscope Co. to become Sperry Rand.

Note. A United Kingdom affiliate of James Powers' US company was founded in 1915 under the name Powers Samas. In 1959 it became International Computers and Tabulators Ltd. (ICT), by merging with British Tabulating Machines (UK), the latter being a subsidiary of IBM (formerly CTR; see Box E). Further the mergers with English Electric and Marconi gave the new name of ICL (International Computers Limited), which in the early-1980s became a part of the Standard Telephone and Cables (STC) company.

before their acquisition by what was to become, in France, the Société des Machines Bull.

4.4. Thanks to a technological evolution – which, with the hindsight of several decades, may be thought a matter of course, but which called for much resourcefulness and audacity on the part of the industrial managers involved – the companies founded by (or named after) Hollerith, Powers and Bull were amongst the foremost manufacturers of electronic computers in the nineteen-fifties. Thus:

- International Business Machines (IBM) in the United States (with its foreign subsidiaries all over the world) is a direct descendant of the company founded by Hollerith;
- Remington (-Sperry-) Rand in the United States and International Computers Limited (ICL) in the United Kingdom used James Powers patents as foundation stones;
- La Société des Machines Bull, in France, is named after the first holder of its original patents.

4.5. In addition to the achievements based on the punched card, reviewed in Sections 4.3 and 4.4, great progress was made in the development of instruments for carrying out arithmetical calculations. The progress made during the years prior to World War I is marked by the names of the mechanical inventors who developed simple and efficient manually-operated devices which could not only add and subtract but also multiply or divide:

- L. Bollée (France) invented a multiplier based on Pythagoras' table, represented by rows of needles – unlike Leibniz's version, which incorporated rotating cylinders along with a device to shift the zero so as to dispose of the sums "left over";
- O. Steiger (USA) in 1895 perfected a machine (the "millionaire", thousands of which were sold) based on the same principle as that of Bollée's device;
- and J.R. Monroe (USA) developed in 1912 an instrument which performed divisions directly and not by means of successive approximations.

4.6. Interest in the development of these arithmetical calculators for office use was, however, very much confined to offices engaged in lengthy and repetitive calculations.

The situation was very different in another industry which "took off" at the beginning of this century – the cash-register industry. Every shop aspiring to attract customers of quality considered it essential for its prestige to display at its

pay-desk a cash-register, shining with its bright metallic parts and ringing each time the lever was pressed to record the sum due. The cash-register was, moreover, of great practical value to both the shop-owner and his staff.

It was the engineer W. Burroughs (USA, 1857–1898), who, in the United States shortly before 1900, and basing himself on previous work of E. Felt, another American engineer, produced the first cash-register which was to come into widespread use. To achieve this, he set up his own company, bearing his name and which, half-a-century later, would be among the big electronic computer companies.

5. Electric relays and computers

5.1. Virtually all the developments thus far described were essentially mechanical in nature, often making very ingenious use of the latest technological advances in this sector of industry. It was exceptional for use to be made of electric relays, only perhaps to operate the bell of a cash-register, [5] for example.

Another exception was the use of electric sensors to detect the punched holes in the cards of the Hollerith and other machines.

5.2. Until about 1930 the use of electrical relays and circuits to perform numerical operations had remained a virtually unexplored field – but for one major exception, based on the highly sophisticated technique of automatic telephone switching. That technique was, indeed, strictly confined to a very limited circle of engineers responsible for the design of switching system circuits [6]. We shall see later on that it was in these circumstances that the honor of making the first numerical computer fell to a researcher with Bell Laboratories, G. Stibitz – who was, moreover, a gifted mathematician (see Chapter III-2).

Box G

Torres y Quevedo

Torres y Quevedo (Spain, 1852–1932), a man of many parts [see Note 1], was deeply interested in calculators and automata. He opened the way for electromechanical technology, (i.e. relays), to implement Babbage's ideas for calculator designs. In a 1914 report to the Madrid Royal Academy of Science, he was the first to call this new branch of science "Automatics" [see Note 2]. He was the inventor of a formal description language using alphabetical/numerical characters and punctuation symbols to give an accurate geometric definition of any piece of mechanical equipment. As an example of the use of this specification language, he produced a full description of a device for computing the product of two complex numbers (real and imaginary parts).

[Note 1. As a structural engineer, he designed and build the cablecar at the Canadian Niagara Falls. It was used by hundreds of thousands of tourists, until recently replaced.

[Note 2. Essais sur l'automation. Sa définition. Etendue théorique de ses applications, Revue de l'Académie Royale de Madrid, 1914.]

5.3. Before describing the family of relay-based computers which was developed in the Bell Laboratories between 1939 and 1950, we must – in order to keep a chronological sequence – mention Torres y Quevedo (Box G), who was amongst the first – if he was not, indeed, the first – to introduce the electric relay to the design of a machine based on that of Babbage.

[5] The device of a bell ringing each time the till was opened (the cashier being the only person allowed to do so) led to the outstanding success of one make of cash-register!

[6] The engineers in charge of the actual running of automatic exchanges had, for their part, to cope as best they could with interpreting and understanding blueprints and learning them by heart. Scant thought was given at the time to enabling the latter group of engineers to enter into the mysteries of the logic governing the various operations involved in putting through a telephone call.

6. The technological and the economic environment in 1940

6.1. Every technique depends for its development on the prosperity of the industries using it. They, in turn, depend on the markets they can develop. In other words, progress in any area of technology depends essentially on the technological and the economic environment specific to that area. What, then, were the markets prior to World War II for firms selling calculating machines?

6.2. Public authorities and large commercial undertakings were the main customers for punched-card machines. The only three or four manufacturers existing in the world had the advantage of a very buoyant market and enjoyed a prosperity which was either exceptional or good. Their fierce commercial aggressiveness led them to do so well that several of them could afford to assume the role of scientific benefactors of renown American universities.

6.3. In addition to these groups, which were by now multinational companies with a number of foreign subsidiaries, there were several more modest companies engaged in a wide range of activities, mainly aimed at retail business: these activities included the supply of cash-registers, automatic weighing machines and many other instruments concerned with weights and measures.

6.4. Mention must be made of the manufacturers, very few in number, who confined themselves to producing small mechanical calculators for office use. These machines were operated manually by turning a handle for each operation. Their manufacturers had a very narrow range of customers: offices engaged in computations, mostly in scientific work such as astronomy or geodesic measurement, in the establishment of range tables for artillery or actuarial tables for insurance companies.

7. Computers change the functions of the engineer

7.1. The appearance of electronic computers at the end of World War II was to bring about far-reaching technological changes. Some problems in science and engineering could now be thoroughly investigated. The art of the engineer was to a large extent transformed.

7.2. The precision sought in his calculations could be significantly increased. Prior to World War II, most calculations were carried out to an accuracy of one-hundredth, in some cases to one-thousandth. In structural engineering, where the concept of a safety factor – inevitably somewhat arbitrary – had to be applied to the results of detailed calculations, the multiplier effect of the safety factor simply ruled out any preoccupation with maximum precision. Of course a safety factor did not enter into all engineering calculations: in telecommunications, as a rule, such factors did not have to be applied. An excellent example is provided in telephone transmission studies by the calculations made during the 1930s for the design of electric filters. This example is relevant to this book since it was for electric filter designs that Bell Laboratories decided to make available to G. Stibitz the funds to design the first scientific computer (a relay-based computer – see Chapter III-2).

During the thirties, the engineer, much as did the architect, most often used graphical methods – for example in plotting curves to show the variations in a parameter or in using nomograms or graphical two-coordinate charts. He mostly relied on his slide-rule. And if somewhat greater precision was needed than that given by the slide-rule, standard practice was to turn to logarithm tables.

7.3. The need for instruments that could calculate rapidly and to a higher degree of accuracy became steadily greater. Mathematical processes had been worked out with innumerable potential applications, but during this pre-1940 period they were considered as being purely theoretical con-

cepts, not applicable to everyday practice. Thus:
- differential equations had been solved by classical mathematics, but proved to be virtually insoluble when, in the world of engineering reality, the number of parameters became large;
- although the theory for calculating determinants or matrices with given values was well known, engineers avoided applying it in practice, if a large volume of data was involved.

There were a number of attempts, albeit scattered, to make algorithms and mathematical computing tools available in a usable form. The practical uses to which such tools were put, however, remained virtually nil. The mathematics-based economy, which had at the time scarcely been born, was simply unaware of the existence of mathematical tools for data-processing – tools for which the economy of today provides one of the biggest markets.

8. The impact of the over-riding needs of national defense: analog-based solutions

8.1. As has often – or all too often – been the case with the development of technology, it was the essential military requirements which became especially acute during the thirties, prior to World War II, which led to major progress in the art of automatic computing.

A typical example of a major problem, crucial at the time, is the anti-aircraft gun. To hit a rapidly-moving target, the gun's aiming mechanism must work out, in a few seconds, the coordinates of the point at which the path of the aircraft will be met by the trajectory of the shell. A difficult problem !..

8.2. The solutions sought and found at that time were those which are today called "analog" - as distinct from "digital" solutions obtained by processing of digits. Sliding devices or cursors (often elaborately shaped) moved in front of scales or dials and constituted the links between the devices for target display and those for aiming .... All these were, in fact, no more than developments and refinements of mechanisms which had been in use for over half a century, particularly in naval gunnery. With luck, the shots fired sometimes scored hits on their rapidly-moving target in the sky ...

8.3. In the quiet environment of their laboratories, scientists had already developed devices of the same analog nature – often even before the beginning of this century – for tasks such as the harmonic analysis of wave phenomena or the solution of differential equations. Even more simply, the planimeter was employed to obtain the integral of a function by measuring the area enclosed by a curve. In the United States, the Massachusetts Institute of Technology (MIT), under Prof. Vannevar Bush, mathematician and electrical engineer, was a focus of activity in this field.

8.4. In this Chapter we limit ourselves to this brief reference to that field of research devoted to analog computation – a field which continues to be the subject of some activity, resulting in devices and systems either wholly analog or hybrid in character, the latter making use both of analog devices (such as sensors or control mechanisms) and of digital calculators.

We will not, however, elaborate further on the subject of analog computing systems, for although SPC switching systems (both of the space-division and time-division types) are related to and can, indeed, be said to be descended from the electronic computer, their relationship lies purely in the digital concept of the switching systems and of their processors.

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CHAPTER III-2

THE COMPUTER ANCESTORS OF THE 1940s
EMERGENCE OF THE BASIC CONCEPTS
WHICH LED TO ELECTRONIC COMPUTING THROUGH THE NEXT DECADES

"It is unworthy of excellent men to lose hours like slaves in the labor of calculation which could safely be relegated to anyone else if machines were used".

[Leibniz, quoted by Goldstine, p. 8]

1. The birth of three basic concepts

Three revolutions can be detected as marking this period of first appearance of fast, reliable(?), and powerful computers:

- the change-over from electromechanical technology to the employment of vacuum tubes;
- the idea of the "stored program", i. e. putting the program – a sequence of instructions – in the memory of the machine, a mode of operation consistent with the existence or development of memories of sufficiently large storage capacity;
- the rather slow evolution which took place from initially a machine-registration of the numbers in the traditional decimal form to the generalized adoption of binary digits.

2. Electromechanical computing machines of the 1935–1945 period

2.1. Two families of this type, using relays for memory storing and stepping switches for counting, and transmitting numbers as electrical pulses on wires, were designed and built in the United States: one family in the Bell Laboratories, the other at Harvard University (Boston, Mass.).

2.2. Bell Laboratories machines, G. Stibitz [1,2]

G.R. Stibitz (Fig. 1), a mathematician at Bell Laboratories, started in 1937 to use relays and other components of the telephone art to build a calculator. What was for him initially a home ("in the kitchen ...") hobby experiment, made up with scrap parts of telephone switches, became in 1938 an official Bell Labs project intended to handle "complex numbers" (with their real part and imaginary part) and subject them to the four operations of addition, subtraction, multiplication and division. The project was to provide an

Fig. 1. G. Stibitz

efficient instrument for the transmission engineers engaged on the intricate design calculations for the high-performance electric filters needed in the terminals of frequency-multiplex systems.

Completed in October 1939, the " Complex calculator", later renamed "Bell Labs Relay Computer Model I", began routine operation in January 1940. [1] The calculator used standard teletype machines as input and output devices. Two, and later three teletypes installed in different parts of the Bell Labs building could have access to the calculator, using it on a first-come first-served basis.

In September 1940, G. Stibitz had been asked to present a lecture before a meeting of the American Mathematical Society at Dartmouth College in Hanover, a New Hampshire city. "A teletype connected to the calculator in the Bell Labs had been installed in the lecture room. At the end of his lecture, Stibitz invited the audience to submit calculations to be performed by the remote calculator. The teletype writer printed out the answers in less than a minute...". This experiment is now recorded in telecommunication history as the first act of data transmission with direct input to a computer from a remote location via a communication link [2].

Initially the Stibitz calculator for complex numbers was almost spiritless. The operator sent it pairs of complex numbers by teletype and it sent back their sum, difference, product or quotient, also by teletype. By 1943, however, a new version of the relay computer received its instructions in sequence by means of a paper tape giving the numbers to be handled and the sequence of operations to be performed on them.

During World War II, a number of more elaborate relay computers, listed as Models II–VI, were built for military purposes by the Bell Laboratories. A description of the characteristics of these models is given in condensed form in [3]. Their detailed description appears in Volumes of the series "A History of Engineering and Science in the Bell System" (HESBS) [4].

[1] The design engineer was S.B. Williams, later (1952) president of the "Association for Computing Machinery (ACM)" and also an inventor of electronic computers which were for many years in patent interference with some of the computers mentioned later in this chapter.

2.3. The Harvard University machine, H. Aiken [5,6a]

2.3.1. In 1941 at Harvard University, Howard Aiken, a physicist-mathematician, with IBM funding support and the cooperation of IBM assistants, put into service another relay computer initially designed for the calculations of the T.J. Watson Astronomical Computing Bureau at Columbia University. When beginning its work in April 1944, the computer was used to do calculations for the U.S. Navy.

This computer is known under the name either of "Automatic Sequence-Controlled Calculator" (IBM terminology) or of Harvard MARK I. Its design involved 800,000 pieces of equipment, all of an electromechanical nature, most of them obtained from pieces of IBM punched-card machines. Input and output data were on IBM punched cards. A punched paper tape – an embryonic program – gave the orders controlling the action of the various registers (adders and units for multiplication and division).

Harvard MARK I was followed by three other versions, Harvard MARKs II, III, and IV, which appeared in 1947, 1949 (a version with electronic tubes and a drum memory) and 1952 (one of the first with ferrite-core memories).

2.3.2. For its own part, IBM developed its "Selective Sequence Controlled Electronic Calculator" (SSEC) [6b] between 1945 and 1948. This large computer was in the tradition of the Harvard MARK design but incorporated some important innovations: firstly, a limited introduction of electronics (with many vacuum tubes but even more electromechanical relays); secondly and more specifically, programming in memory, albeit through a three-level hierarchy of memories:

- a very small electronic (tubes) memory,
- a larger one of the relay type, and

– mainly a prepunched tape memory containing initial data, tables of functions and program instructions.

Some writers have paid their tribute to IBM by claiming that the IBM SSEC can have the distinction of being regarded as the first electronic computer...[6c].

3. Advent of the first electronic computers

3.1. The Atanasoff project [7,8]

The first known attempt to build an electronic calculating machine is attributed to John V. Atanasoff. As an applied mathematician at Iowa State University, he had to make long calculations to obtain approximate solutions to large systems of linear algebraic equations. His knowledge of the virtues of the Eccles-Jordan flip-flop led him to consider an electronic approach to designing a digit calculator. Thanks to the confluence of his mathematical education and his expertise in the electronics of his time, he also discovered all the advantages of using a "base two" number system in a number calculator. He was indeed an initiator in several fields, even if, in the list of honours of the founding fathers of the electronic computer, he was all too often forgotten until recent years [7].

In 1936–1937 his initial design approach, consisting solely of using binary counters made up of tubes, became more elaborate and he conceived a system employing memory and logic circuits: punched cards had to provide the memory.

A grant from Iowa State University had allowed him to start constructing his computer. He was halfway through his enterprise (the electronic part was said to be operational) when in 1942 he had to leave the University and join the Naval Ordnance Laboratory for military service. His machine was then abandoned and never went into operation.

3.2. The ENIAC computer. Mauchly and Eckert [9,10]

3.2.1. Mauchly (1903–1980), after a Ph.D. degree in physics, became professor of physics at a Pennsylvania College. He was doing research there in meteorology, for which he had to perform laborious computations. Having to use mechanical tabulating equipment, he dreamed of an electronic version using vacuum tubes.

In 1941, while taking a summer course in advanced electronics in the Moore School of Electrical Engineering at the University of Pennsylvania in Philadelphia, his talents were appreciated and he joined the staff of the institution as an instructor.

Moore School was doing contractual defense work for the Ballistics Research Laboratory (BRL) of the Army Ordnance Department, located at Aberdeen near Philadelphia. BRL was in a tight need of outside assistance in computing range tables for artillery, a process involving very long calculations then performed with mechanical desk-top calculators. In other countries, military departments had been doing this work for decade after decade, with large staffs specialised in such computations. That had not been the case in U.S.A. and the matter was now urgent.

Mauchly, in a 1942 memorandum entitled "The Use of High Speed Vacuum Tube Devices for Calculating", had submitted his ideas to H. Goldstine, BRL's liaison with the Moore School. His ideas led to a large contract from BRL for the Moore School to build a powerful electronic computer, the "Electronic Numerical Integrator and Computer", better known by its acronym ENIAC [2]. The ENIAC project began in 1943 and the computer was delivered for service in 1946 (when the war was over !..). Intended primarily for ballistic computations of range tables for artillery shells, ENIAC was a fast calculator: doing an addition in 0.2 millisecond, in half a minute it could calculate a range table that formerly took 20 hours.

3.2.2. The ENIAC architecture was a transposition into electronics of the mechanical calcula-

[2] "In the name ENIAC, where the "I" stands for "Integrator", the use of this word was devised to help sell the Pentagon that what the BRL was getting would compute firing tables" (quote from J. Eckert in Metropolis, p. 526)

tors. It had a decimal structure, with "decade ring counters" formed by 10 flip-flops to register (read and write) a decimal digit. There were arrays of these decade counters to form an "accumulator" (a total of 20 accumulators in the machine) to register a decimal number, the length of which was up to 10 decimal digits, plus the sign of the number (a binary counter). Hence a multitude of tubes, plus, for what is now known as a read only memory (ROM), a large "resistor matrix circuit" [10].

ENIAC was a very large machine using about 18,000 tubes of 16 different types operating at 100 kHz, and, in addition, several tens of thousands of resistors and capacitors, plus 6000 switches. Many were afraid that, especially due to the large number of tubes, the computer would never be able to operate reliably. It did, however, though not without difficulties:

Quotation from A.W and A.R. Burks [11]: "It required the development of specific circuits that would operate at the desired speed" (100 kHz) "and their combinations into larger circuits in such a manner that the entire system would operate reliably and could be maintained."..''Such complex electronic equipment had never before been built or even contemplated. Not only was the ENIAC large, with tens of thousands of interacting components, but the parameters of these components were subject to considerable variation. The operating characteristics of the vacuum tubes especially varied from tube to tube and also with age." (end of the quotation)

3.2.3. With the name of Mauchly, the one of J.P. Eckert [3] was to become associated: he was, then a 28-year-old electrical engineer, the chief engineer of the project, Mauchly having been made principal consultant. The actual design of the electronic circuits, with all the difficulties quoted above, was the work of Eckert, in close association with a team of other young engineers, especially Arthur W. Burks. Seeing the importance of reliability for such a large machine, Eckert imposed severe safety factors on all elements of the electronic circuits. In the architecture of the system he applied the now so popular principle of "modularity", with few basic circuits forming its "building blocks".

3.2.4. Mauchly and Eckert, co-inventors of the ENIAC, were enterprising men. After the success in 1946 of their computer, they left the Moore School and formed a partnership to study and build another computer intended to enable the National Bureau of Standards (NBS) to process the data of the American census of 1950. It had to be an EDVAC-type machine (see under 4.2) and was the one which later became known as UNIVAC, for UNIVersal Automatic Computer.

The Eckert-Mauchly Corporation encountered delays in the realization of their new computer, patent litigation (referred to above in footnote 1) and finally financial difficulties which obliged them to agree to the takeover of their company by Remington Rand. The UNIVAC I delivered by this Company was in operation in 1951: it was a commercial product and it is said to have been the world's first business electronic computer [4].

[3] In the history of the 1940s American computers there are two engineers of the name of Eckert, who should not be confused by readers:

- John Prosper Eckert Jr., the co-inventor with J.W. Mauchly, at the Philadelphia Moore School, of the ENIAC machine,
- Wallace J. Eckert who worked with Prof. Aiken for the Harvard Mark I project and later with IBM for its SSEC computer.

[4] UNIVAC (Remington Rand), with the ERA 1101, were the first commercially-produced electronic computers in the United States. They bridged the gap between university and military funded computing projects of the 1940s and the fledgling of the computer industry of the 1950s.

UNIVAC was introduced into homes across America by a CBS broadcast during the 1952 Presidential election for an early forecast of the ballot results: at 8.30 pm, with only a few million votes tabulated, a UNIVAC machine determined the projection of the balloting [12].

Fig. 2. J. von Neumann

4. The "stored program" concept [13–17]

4.1. The idea of the stored-program-controlled computer, a decisive innovation in electronic design, is almost universally (however, see [13]) attributed to John von Neumann (1903–1957), one of the great names in the history of science in our century (Fig. 2). A polyglot in seven languages, he was a man of outstanding intelligence. He is considered as one of the best mathematicians of his time, with studies which extended into many different fields, from mathematical logic and the theory of sets to the axiomization of quantum mechanics (1932), and from the "theory of games" based on operational calculus (a 1944 best-selling scientific work in coauthorship with O. Morgenstern) to his decisive contributions to the logical design of electronic computers.

After studies in Berlin, Budapest and Zurich, Hungarian-born John von Neumann came to the United States in 1930 and joined Princeton University, becoming in 1933 a permanent member of what became the world-wide famous Princeton "Institute for Advanced Studies" [14]. His participation during World War II as consultant in the Manhattan Project (the atomic bomb) at the Los Alamos Laboratories obliged him, although he was mainly concerned with high-level theoretical aspects of physics and mathematics in the design of the bomb, to carry out extensive and intricate calculations; thus he became a great user of the early calculating machines then in existence. Through a fortuitous meeting in a railway train with H.H. Goldstine, a member of the team which was building an electronic calculator at the Moore School of Philadelphia, von Neumann visited the Moore School in September 1944, was greatly interested and repeatedly offered his views on the design of the machine.

4.2. When ENIAC was still under construction in 1944, the Army asked the Moore School to build another version of its machine, a more powerful one to offer higher performance, which received the name of EDVAC (Electronic Discrete Variable Automatic Computer). Once again von Neumann offered his views on the design of the new machine. His paper [15a] embodied the simple and remarkable idea of the "stored program". Instead of entering instructions on punched paper tapes or using plugboards, the program would be stored in the (electronic) memory of the computer as addressed numbers and would be handled in the same way as other numerical data [16].

These ideas were again developed in a two-month seminar held at the Moore School in the Summer of 1946 and attended by 30 professionals drawn from twenty American and British organizations [15b] (see Box A).

4.3. The impact of the stored program concept – "a stroke of genius", it has been said – was decisive for the design of the electronic computers which were to appear in the following years and for decades to come. All current computer systems nowadays are still based on what is called a "von Neumann machine architecture", characterized by the following features [18]:

- there is a single sequentially addressed memory,
- a program is stored in the memory, with its instructions referenced by their addresses in the memory,
- there is no explicit distinction between instructions of a program and the data the program has to process.

Box A

The von Neumann Report (1946) "Computer Design Development"
(significant extracts) *

1. General design

... Conceptually there are two different forms of memory: storage of numbers and storage of orders. If, however, the orders to the machine are reduced to a numerical code and if the machine can in some fashion distinguish a number from an order, *the memory organ can be used to store both numbers and orders*. If the memory for orders is merely a storage organ there must exist an organ which can automatically execute the orders stored in the memory. We shall call this organ the Control.

Inasmuch as the device is to be a computing machine, there must be an arithmetic organ in it which can perform certain of the elementary arithmetic operations. There will be, therefore, a unit capable of adding, subtracting, multiplying and dividing.

2. Memory

2.1 General Remark

The size of the memory is a critical consideration in the design of a satisfactory general-purpose computing machine. We plan on an electronic storage facility of about 4,000 numbers of 40 binary digits each.

2.2 The memory organ

2.2.1. One criterion for the storage medium is that the individual storage organs, which accommodate only one binary digit each, should not be macroscopic components, but rather microscopic elements of some suitable organ. They would then, of course, not be identified and switched to by the usual macroscopic wire connections, but by some functional procedure in manipulating that organ.

One device which displays this property to a marked degree is the iconoscope tube. In its conventional form it possesses a linear resolution of about one part in 500. This would correspond to a (two-dimensional) memory capacity of $500 \times 500 = 2.5 \times 10^5$. One is accordingly led to consider the possibility of storing electrical charges on a dielectric plate inside a cathode-ray tube. Effectively such a tube is nothing more than a myriad of electrical capacitors which can be connected into the circuit by means of an electron beam ...

The Princeton Laboratories of the Radio Corporation of America are engaged in the development of a storage tube, the *Selectron*, of the type mentioned. This tube is also planned to have a non-amplitude-sensitive switching system whereby the electron beam can be directed to a given spot on the plate within a quite small fraction of a millisecond ...

2.2.2. Other stages in the storage hierarchy

A second form of storage must be a medium which feeds blocks of words to the electronic memory. It should be controlled by the control of the computer and is thus an integral part of the system, not requiring human intervention...

The storage medium should be capable of remembering very large numbers of data at a much smaller price than electronic devices. It must be fast enough so that a large percentage of the total time is not spent in getting data into and out of this medium and achieving the desired positioning on it.

* The numbering of paragraphs is not the original numbering of the report (which was far more lengthy than the short extract text above). Italics were not in the original text and have been inserted in the present Box.]

Box A (continued)

Both light- or electron-sensitive film and magnetic wires or tapes, whose motions are controlled by servo-mechanisms integrated with the control, would seem to fulfill our needs reasonably well ...

Lastly our memory hierarchy requires a vast quantity of dead storage, i.e., storage not integrated with the machine. This dead storage is to be considered as an extension of our secondary storage medium.

3. The Arithmetic Organ. Use of Binary Digit System

In a discussion of the arithmetical organs of a computing machine one is naturally led to a *consideration of the number system to be adopted*. In spite of the longstanding tradition of building digital machines in the decimal system, we feel *strongly in favor of the binary system* for our device. Our fundamental unit of memory is naturally adapted to the binary system since we do not attempt to measure gradations of charge at a particular point in the Selectron but are content to distinguish two states. The flip-flop again is truly a binary device.

The main virtue of the binary system as against the decimal is, however, the greater simplicity and speed with which the elementary operations can be performed. In *binary multiplication* the product of a particular digit of the multiplier by the multiplicand is either the multiplicand or null according as the multiplier digit is 1 or 0 ...

An important part of the machine is not arithmetical, but logical in nature. Now *logics*, being a yes-no system, *is fundamentally binary*.

It is only recently that for new, very fast and very powerful computers (e. g. for artificial intelligence machines), designs for "non-von Neumann machines" using parallel processing instead of von Neumann sequential processing are beginning to be considered.

4.4. The von Neumann mathematical perspective tended to draw his attention essentially to logical structures of a computer and to consider it as an abstract machine. Three sources can be discernible in the mathematical expertise he applied to his computer designs: – mathematical logic, – "computing problematics", – and the Leibniz's ideas for the use of a system of binary numerals.

a) Mathematical logic had been initiated by George Boole (1815–1864). Claiming that logic should be a science branch of the mathematics and not of the philosophy, he was the founder of this now so important field of mathematics. In the 1840s he was the inventor of the "Boolean" algebra and its famous system of notations for representing logical propositions in algebraic terms. After many years of oblivion, the Boolean algebra [5] was rediscovered by some communication engineers at the end of the 1930s (Nakasima and Hanzawa, in Japan; Shannon, Keister and Joel in USA; Zuse in Germany; Gavrilov in USSR) and, from the 1940s and even more the 1950s, became a basic tool for the design of logic circuits.

Pure mathematical logic, in the wake of Boole's works, started coming into its own towards the end of the nineteenth century with demonstrations of theorems and the appearance of logic systems put forward by Frege (1848–1925), Whitehead, Russell and many others.

b) The 1930s saw the emergence of new ideas on what became known as "computation problematics", an abstract concept encompassing not only "numbers" but also all the symbols for formalizing the operations required for their manipulation and deciding on how they should be processed. A. Turing (1912–1954) conceived in 1937 at Princeton, with the presence of Church, the principle of his universal machine, demon-

[5] see Box B of Chapter II-2

strating that "numbers" were after all only one of several ways of interpreting the internal state of the machine.

c) The use of binary numerals is the subject of the following section 5.

5. Number representation in a computer. Advent of the use of binary digits to express the numbers

5.1. The man in the street is now quite familiar with the binary number concept and even with the extraordinary convenient word "bit" coined in 1948 [6] as a shortened form of "binary digit". So widespread has the use of the word "digit" become that in everyday parlance nowadays the key adjective "binary" qualifying the word "digit" has been dropped from the original expression at the risk of losing the meaning of binary. Now we refer to systems instead as only being "digital", an up-to-the-minute term which the media and admen are constantly using – and in all country languages – to sing the praises of new systems of our modern time.

Things were very different prior to the mid-1940s, when the binary numeral concept was still regarded simply as a mathematical curiosity known only to a handful of academics, one which was passed over in total silence in the teaching of mathematics where it was looked upon as a somewhat trivial matter, and even more so at engineering schools. Leibniz's propositions demonstrating the usefulness of the binary system for multiplication purposes were blissfully ignored in mathematics, as well as by the manufacturers of mechanical calculating machines.

5.2. The honour of reviving Leibniz's ideas must go to three persons working independently, namely:

- L. Couffignal in France, in 1936 [21]
- K. Zuse in Germany, in 1939 [22]
- J. von Neumann in the United States, in 1946.

[6] The term "bit" was not coined by C. Shannon as many think, but by J.W. Tuckey at Bell Laboratories [20].

Each contributed in his own way and with such authority as he had. Indeed, the impact of their individual pleas for the binary system to be used in calculating machines differed greatly:

- an insignificant one in the case of Couffignal, a young teacher whose first attempts to help in the construction of a calculator in France were abruptly ended in May 1940 by the German occupation;
- a very limited one in the case of Zuse who succeeded, not without difficulty and indeed with very little material support from the authorities of the Third Reich, in building several models of calculating machine during the war years; all of them were based on a system of binary notation and the last two, as a result of cooperation with H. Schreyer, were of the electronic type (see Box B). All these models were lost during air raids or events after the war, so Zuse's work went largely unknown for practically 20 years;
- von Neumann's contribution, on the other hand, came as a bombshell for three reasons: his standing as a scientist and the tremendous authority he enjoyed in university and political circles; the clarity with which he expressed his ideas (see Box A, under 3 of this Box) and, lastly, the environment and age in which he started advocating use of the binary system in computers. The environment was that of the United States, the age that of the post-war period immediately following the scientific breakthrough of the first atomic explosion, an enterprise to which von Neumann made invaluable contributions.

5.3. An overview of the numbering notation systems used in computers prior to the Zuse models and the triumph of von Neumann's ideas

5.3.1. When using bistable devices such as relays, a natural way to apply them to number storage would have been to convert numbers from the decimal to the binary system and store them in the latter form. But the length of a binary number (we would now say a length expressed in bits) is far greater than the length of the same number in decimal notation and this

implies a larger storage unit. Moreover, there is also the need to convert input decimal numerals into binary numerals and, for the output, vice-versa.

5.3.2. We have already seen that the ENIAC computer was a pure "transposition" of a decimal calculator and used exclusively decimal digits. To register and process numerical data the

Box B

Konrad Zuse [22,23,24]

Konrad Zuse, a young German engineer with a degree in civil engineering, is to be regarded as an originator of two fundamental numeral concepts in computer science:

1) the use of the binary number system for the purpose of performing arithmetic operations along with efficient algorithms for conversion from decimal to binary and vice-versa;
2) the use of the floating radix point (in parallel with what Stibitz did in the same years for his first Bell Laboratories' model, but completely independently and in ignorance of Stibitz's achievements).

In a 1936 patent paper, he was one of the first to advocate the use of a binary numeral system in a computing machine: "One can discard human habits and choose the simplest numeral system, i. e. a system with the base "2". Leibniz has already recognized the advantages of what he called the "Diadic" system. This insight is also valid for the computer. The ideas of building counters and such like in a binary system are not new." But they were ignored.

"In the beginning of my work, I discovered the analogies between switching circuits and the calculus of propositions and a switching algebra was set up. With H. Schreyer, we discovered that all calculation operations can be divided into three basic operations of propositional calculus and Schreyer developed the appropriate electronic components for these three operations."

Six successive models of computers were built in Germany by Zuse:

- the first one, Z1 (1938), with mechanical technology,
- its successors (Z2, Z3, Z4, S1, S2), with electromechanical relay technology,
- plus two others in the same line of conceptual design but with electronic technology, the first built in 1938 and the second in 1944 in cooperation with H. Schreyer at the Technical University of Berlin.

All of these eight models were operating with numbers expressed in binary digits.

Aiken's MARK machines at Harvard were also using decimal counters.

By 1939 IBM Laboratories at Endicott, NY, had discovered the possibilities offered by what they called "triggers", that is to say the Eccles-Jordan "flip-flops", for registration and processing of binary data and they were considering an application of this electronic technology for the construction of an arithmetical calculator. However, since all commercial devices were using the decimal system, their first electronic development was oriented towards the design of decimal (base 10) counting units. (At Harvard, Aiken was working in close association with IBM and that was perhaps a reason for his choice of a decimal architecture for his MARK machines.)

5.3.3. For the two reasons mentioned under 5.3.1, Stibitz, as a mathematician who was well aware of the virtues of binary numerals, had adopted a very specific system of his own, similar to the one used in the Chinese abacus, the "bi-quinary system", to register decimal digits in his successive computer models. A decimal digit was replaced by two digits, of which one (the "quinary" digit) had one of the values from 0 to 4 and the other (the "binary" digit) had one of the two values 0 or 5, in such a way that the sum of the two values was equal to the value of the decimal digit to be registered. This method implied 7 relays to register a decimal digit.

The decimal numbers which the Stibitz machine could register had seven significant decimal digits, its sign (+ or −) and, according to the common practice of logarithmic calculations, a digit that was the exponent of the power of ten by which the decimal number was to be multiplied. The Bell Labs machine is thus [7] considered as the first to use a floating decimal point, a practice which was to become very generalized in the years from the mid-1940s.

[7] With the Zuse computers, it should be remembered.

6. A brief worldwide survey of computer studies until the early 1950s

6.1. Mass-media had given a large publicity to the ENIAC achievements and worldwide public opinion had been impressed by the spectacular results obtained with this electronic machine. The participation of top-level scientists to the 1946 summer course at Moore School had had a large impact upon the academic circles (Fig. 3). With the experience drawn in USA from computer usage for defense needs, Military Departments of all important countries were anxious to follow the American model and take advantage of the possibilities offered to their arsenal offices by this new, modern, and efficient tool. It was no surprise therefore that allocations of governmental budget funds were easily granted in many countries for research and development of computers to be designed and manufactured locally.

Many electronic computers were thus built in several countries in the last years of the 1940s, though they more generally appeared in service during the early 1950s. They were for the most part experimental models designed at research institutes associated with universities, and some of them were built by industrial firms of the telecommunication industry. The list of these early computers is a long one. For most of them we shall find a short reference in the following Chapter III-3, where they are listed according to the basic type of the memories they used:
- cathode-ray tubes, section 3.4;
- magnetic drums, section 4.4.

6.2. We have already seen what had been in Germany a limited-scale computer development by Zuse and Schreyer during the war-years.

Due to the important position in computer research that British scientists held in the post-war years, we give here a short chronological account of the major contributions to the computing and programming science which mark British achievements of this period.

6.3. Computer developments in United Kingdom

(1) 1941–1945: the COLOSSUS cryptographic machine (see Box A in Chapter II-5). Among its

Fig. 3. The 1946 Summer Course at Moore School photograph. Many of the computer pioneers are present. From left to right: standing: T.H. Flowers, Grace Hopper (the first programmer, Harvard Mark I), J.H. Wilkinson, T. Kilburn, M.Y. Wilkes; sitting: F.C. Williams, E.A. Newman, K. Zuse and *alia*.

designers, besides T.H. Flowers, A. Turing and Prof. M.H. Newman.

(2) 1945: Foundation of the National Mathematical Laboratory, initiating two advanced research projects on computers at the Universities of Manchester and Cambridge:

(3) 1947–1949:

(3.1) At Manchester University, a team under the direction of Professors N.H. Newman and F.C. Williams built between 1947 and 1949 the "Manchester machine" or, more officially, the MADM (Manchester Automatic Digital Machine). It was for this machine that F.C. Williams invented [8)] the electrostatic cathode-ray tube, the famous Williams tube (see Chapter III-3, section 3), to be used for the "registers" providing its "store" (what would now be known as its memory). The machine was equipped with 256 of these tubes.

Other improved models of the MADM machine were built in the following years by the British firm of Ferranti. This company has been considered as the first in the world to make a computer as a commercial product, its Ferranti Mark 1 having been put into service in February 1951.

(3.2) The EDSAC (Electronic Delay Storage Automatic Computer) was built under the direction of Prof. M.V. Wilkes at Cambridge University during the same period. Its memory used 1024 registers which were ultrasonic delay lines. The machine has often been cited as the first all-electronic computer embodying the stored program concept advocated by von Neumann for the design of the American EDVAC project.

(3.3) The operation of the Manchester and Cambridge machines marked the very beginning of what was to become the art of programming (see Chapter III-4). An historical example of the advances in this field is the chess-play program developed by A. Turing, which was demonstrated on the Ferranti Mark 1 machine installed at the Manchester University.

8) Patent of Dec. 14, 1946.

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CHAPTER III-3

THE 1950s: THE MEMORY RACE [1–7]

1. The race for fast memories

1.1. The rapid progress made in the first generation of electronic computers was largely due to improvements in the design of memory units. The now historic and prophetic von Neumann report (see Box A in Chapter III-2) written in 1946 on the prospects being opened up for all electronic computer architecture by the technology of the day had already drawn a basic distinction, which was to become a constant in all electronic equipment architecture, between:

- the main memory serving in the "machine" core and requiring an extremely fast basic cycle but not a high storage capacity,
- and the secondary memories for mass storage, which might have a fairly long access time.

1.2. The only mass memories available during the immediate post-war years had been the ones perfectly familiar for several decades:

- punched paper tape as used by Turing in designing his mathematical machine and by Stibitz at Bell Laboratories in his relay-operated computers,
- and punched (paper) cards of the type widely used in mechanical data processing.

The electronic computer industry soon demonstrated its spirit of innovation by supplementing punched cards and tapes by magnetic drums and tapes. Introduced between 1948 and 1951, these rapidly became the standard equipment.

1.3. The most spectacular advances were made not so much in the design of mass storage units as in the development of fast mainframe memories.

The very first computers used electronic tubes arranged as flip-flop devices as fast storage. Two vacuum tubes were needed for recording one data bit, although both components could in fact be incorporated in a single envelope. Despite the space taken up by battery up on battery of tubes and particularly because of their enormous power consumption and heat dissipation making the plant operation unreliable, these devices offered only a limited storage capacity.

1.4. In order to equip their computers with more compact and less power-consuming memories, designers turned to innovations made during the Second World War. It was a fairly miraculous stroke of luck in the early infancy of the industry itself: "Revolutionary ideas such as the concept of the stored program normally require for their implementation lengthy and tedious technical developments. Computers were fortunate in that they could be rested on (four) corner stones, represented by (four) technologies which had been developed for other purposes, in different parts of the world, and which were ready for use by anyone who cared to help himself" [8]:

- delay line memories,
- cathode-ray tubes,
- magnetic recording,
- ferrites.

2. Delay line memories

2.1. The radar devices developed during the war required information obtained from the an-

tenna sweep to be stored so as to display a readily intelligible picture of the scanned data on a cathode-ray screen. For this purpose a dynamic memory known as the "delay line" memory had been developed: this consisted of a linear tube into which the data were fed and where they propagated from one to another terminal at a certain speed before retrieval some time later. It was thus possible in a stream of pulses to store a datum which for its further retrieval was shuttled back and forth between the delay line input and output; (in layman's terms, this process may be likened to the way long-distance swimmers perform their laps in an Olympic pool). Several types of delay line, based incidentally on research from 1920 onwards into sonar detectors for anti-submarine warfare, had been developed during the war. Most of these used as input devices piezoelectric quartz crystals which converted a change in the electric charge at the input into a mechanical change and reversed the process at the output; the mechanical changes were converted into acoustic wave pulses propagated in a mercury column (Fig. 1).

2.2. Ever since what some regard as the second electronic computer (or at least one which was the second platoon in the first generation), i.e. the BINAC designed in 1947 by J. Eckert and J. Mauchly and introduced in 1949, the computer's main memory has consisted of delay lines with a storage capacity of 512 words [1]. Delay lines

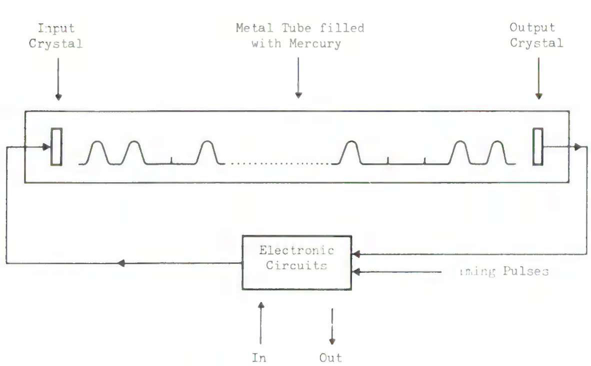

Fig. 1. Delay line memory

also constituted the main memory of the UNIVAC built by Remington Rand in 1951 on a design conceived by those same two engineers [1]. The fast storage capacity of the UNIVAC, with 100 delay lines, consisted of 1,000 words of 12 decimal digits; the machine's data access time was 300 microseconds.

3. Williams' electrostatic cathode-ray tubes

3.1. These tubes (Fig. 2) were named after Professor F.C. Williams of the University of Manchester, United Kingdom [2], who invented them in 1946.

The Williams tube was directly based on the cathode-ray tubes used in television where the screen, struck by the cathode-ray beam, retains a residual fluorescence for a few moments between two successive scannings of the image. If the electrical charges created on the screen are regenerated at sufficiently close intervals, a memory is obtained. The screen of the Williams tube was divided into a number of boxes (or "windows") behind which electrodes were placed to detect the electrical charges. The tube was

[1] The UNIVAC project was initially intended to perform statistical calculations needed for the United States nation-wide census of 1950. The UNIVAC was one of the first computers to be placed on the market. About 15 units were eventually sold.

[2] Scientific cooperation between the United States of America and the United Kingdom was extremely close during the war and in the immediate post-war period. In fact it was in England that the ideas of von Neumann and his design of a stored program machine most quickly caught on. The Universities of Cambridge with Professor M.C. Wilkes (one of the founders of programming theory) and Manchester with Professor F.C. Williams, rivalled each other in producing equipment based on this concept. The Cambridge machine, known as EDSAC and using delay lines as its main memory, was first produced in 1949 (i.e. two years before the similarly-named EDVAC machine produced by J.P. Eckert and J. Mauchly in 1951 following their experience with the ENIAC machine). The Manchester machine and its derivatives are discussed in greater detail below.

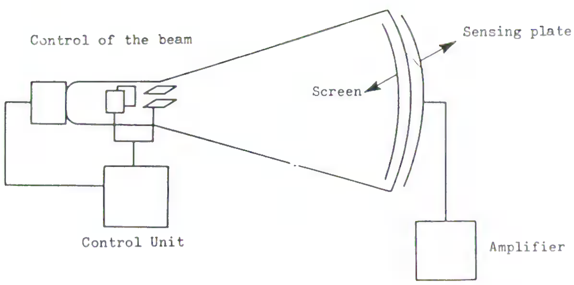

Fig. 2. Williams tube

thus able to store as many data bits as there were boxes in the screen.

3.2. Williams tubes afforded rapid access (some 30 microseconds) to binary data. They were used for the machine built by the Manchester team which Williams formed in association with radar expert Tom Kilburn, the mathematician A. Turing, and a number of the latter's colleagues who had worked on the "cryptanalytic machine" – the COLOSSUS – at Bletchley Park. The Manchester machine [3] and the idea of using Williams tubes as the main memory eventually led to the production of Britain's ACE computer in 1950: this was the Automatic Computing Engine, "the use of the term 'Engine' being in recognition of the pioneering work of C. Babbage on his Analytic Engine" [2, page 102]. The ACE machine was developed with the assistance of the National Physical Laboratories (NPL) at Teddington near London, and later by the English Electric Company.

3.3. In the United States, the same technology using cathode-ray tubes to provide rapid access memories [4] was developed at the M.I.T., Cambridge, MA, by J.W. Forrester (Fig. 3) and A. Haeff.

[3] An experimental machine known as MADM, the initials of its official name: Manchester Digital Automatic Machine.

[4] Williams tubes have been preserved in various science museums [e.g. Museum of Science, Boston; Museum of History and Technology, Washington, D.C.].

Fig. 3. J.W. Forrester holding a ferrite core memory plane

In 1948, J.A. Rachman of the Radio Corporation of America (RCA) also developed a tube on more or less the same principle but with a completely different geometry and no cathode-ray screen. This selective electrostatic storage tube, or the Selectron tube as it was known, is briefly described in [2, page 468]. Over 2,000 such tubes were built and their design had some impact on the telephone industry laboratories engaged in research on electronic switching.

However, conventional Williams tubes were eventually used in the United States:

- for the fast memory of a machine built in 1951 at the Institute for Advanced Studies (IAS) of the University of Princeton (and known as the IAS machine [5]; the machine was designed by von Neumann and Goldstine who had together supervised the development of the ENIAC computer at Moore School in Philadelphia and its introduction in 1949;
- for building, again under von Neumann's supervision, the MANIAC machines (Maniac I in 1951, Maniac II in 1955) developed at Los Alamos to handle that nuclear physics center's calculation requirements;

[5] Still on display at the Museum of History and Technology, Washington, D.C.

- lastly, in 1953, by the IBM Company in the construction of its commercially very successful IBM 701 series.

3.4. Cathode-ray tube memories were also used in the second, third and fourth Soviet computers which were designed by S.A. Lebedev, I.S. Bruk and Y.Y. Baxilevsky, respectively, and known as BESM (BESM-1 in 1952, BESM-2 in 1956), M-2 (1952) and STRELA (1953) [1].

4. The magnetic drum

4.1. In the technology of the 1950s, magnetic drums came into their own not only for the development of electronic computers but also in studies and research into electronic switching.

4.2. An earlier technology developed by the home entertainment industry

Just like the magnetic tape and discs replaced punched cards and paper tapes in computer mass memories, magnetic drums must be regarded as a technological borrowing essentially from the sound broadcasting, film and record industries, otherwise known as the home entertainment sector.

The source of this very old technology is unquestionably an invention by Waldemar Poulsen (Denmark) [6] dating from 1893. Poulsen had taken a patent [9] on what he called the "Telegraphon", an apparatus which enabled sound and voice signals to be magnetically recorded on a steel wire wound spirally around a cylinder, and to be restored by means of a "reading head". Unfortunately, the signal-to-noise ratio of the equipment was terrible and the Telegraphon failed, eventually to be replaced by the cylinders and, above all, discs of Edison's phonograph.

Between 1920 and 1940 a great deal of work was done on magnetic recording in Germany, the United States, the United Kingdom and the Soviet Union with most applications to film, record and broadcasting industries. The armed forces, too, naturally took an active interest in the process.

Two outstanding events in the development of the technology are worth mentioning:

- in 1928, Dr. Friz Pfleumer (Germany) took a patent on a magnetic tape consisting of a coating of metallic powder on a plastic film of the type used in the film industry. (Incidentally, it appears that his invention stemmed from another minor invention of his own concerning improved mouthpieces for filter cigarettes, which were also dusted with metallic powder! ... [6]);
- in 1936 AEG and IG Farben took a patent in Germany on the "Magnetophon" and started marketing equipment under that name.

In the history of the telephone, it will also be noted that magnetic tape made its first appearance in operational services in the years immediately before the war. In 1939, "after public use at the New York World Fair, Bell Laboratories developed their first commercial use, applying them to weather forecasting" [7, p. 42]. Telephone operational services started making wide use of magnetic tape for verbal announcements from the 1960s onwards.

4.3. Magnetic drums for recording data

4.3.1. Their origin and advantages

The use of magnetic drums for recording data rather than sound signals must be ascribed to G. Tauschek (Austria) who, in 1933, took a patent for their use as a data recorder for data processing tabulations [10].

In contrast with the magnetic tapes and discs which were useful only as mass memories in computers, magnetic drums had the great asset of an incomparably shorter data access time. The tapes used in mass memories were sometimes hundreds of metres long, with winding speeds of only about 1 metre per second. The compact

[6] Poulsen ranks among the great inventors. In his own day, he was better known for his invention of electric arc transmitters for wireless telegraphy, which were fairly short-lived, than for his Telegraphon, the forerunner of a technology which, though long disregarded, was to assume major importance in the second half of the twentieth century.

geometry of the magnetic drum – a cylinder with a diameter of about 10 cm – permitted rotation speeds (2,000–12,500 r.p.m.) much higher than that of a magnetic disc of far greater diameter.

In selecting for playback by means of a given address a track recorded on the drum, the use of several scanning heads arranged in parallel on the edge of the drum was far preferable to selecting "one out of n" discs, all piled one on top of another as in the present-day juke boxes familiar to the drinking fraternity.

4.3.2. Use of drums as memories

Offering as they did a large data storage capacity (up to 100,000 bits in the IBM 650), a reasonable data access time, reliability and, above all, a longer life duration than the Williams tubes, magnetic drums experienced a great vogue in the 1950s before being superseded in the sixties by ferrite core memories. They were used mainly as auxiliary or buffer memories to back up the computer's fast memory. In a few cases they constituted the fast memory itself – this was generally the case in the experimental machines produced in university laboratories and in the first generation of magnetic drum computers. Depending on the model of drum used, this type of memory offered an average data access time of between 15,000 and 5,000 microseconds [3, p. 67]. Mechanical improvements, particularly in the bearings, made for increasingly fast rotation speeds allowing reduced access time.

4.4. Use of drums by the computer industry

4.4.1. In the United States

The first machine to incorporate a drum for storage purposes was the IAS machine designed by H.H. Goldstine and J. von Neumann in 1946 and also known, wrongly it seems, under the name of Maniac.

The first drums used in an operational computer were built into a machine designed in 1946 by Electronic Research Associates (ERA) and delivered in 1950. Considered to be extremely efficient, they were the outcome of work conducted at St. Paul, Minneapolis, by engineers associated with ERA and in collaboration with the Georgia Institute of Technology [2]. The system was closely studied by IBM engineers and in fact the company installed drums as the only memory in its mid-range 650 series marketed from 1953 onwards, more than 150 units of which were sold (including two to Bell Laboratories) [3, p. 68]. IBM also used drums, though only as buffer stores, in its 702, 704 and 705 series produced from 1954 onwards, and for a tape-processing machine (TPM) at about the same time. In 1950 when the ERA machine was delivered, H.C. Aiken of Harvard University put into service the third machine of his own design, the MARK III, and its only memory consisted of eight magnetic drums. As early as 1949, General Electric was also using at Syracuse, New York, a drum in an OARAC machine, a computer made for the Office of Air Research.

4.4.2. Outside the United States [1]

Magnetic drums also found great favor in Europe.

In the United Kingdom, Professor Williams abandoned the cathode-ray tube in favor of a drum memory in the new Manchester University machine known as the MARK I (M for Manchester). Descendants of the MARK I, all using drums, included the DEUCE (1955), PEGASUS (1956), MERCURY (1957), ARGUS (1960) and the MK2 machines, most of which were produced and marketed by Ferranti Ltd. and made that company's reputation.

Drums were also used in the auxiliary memories of the computers manufactured by EMI, ICT and Standard Telephones and Cables (STC) between 1955 and 1962 [1, p. 179]. It will be noted in passing that STC operated in the telecommunication sector; after 1960 it abandoned the activities it had started in the computer industry, although magnetic drums played a prominent part in its Harlow Telecommunication laboratories and were to become the favorite toy of E.P.G. Wright, a prolific inventor. Wright, who originated many patents, used drums for numerous experimental electronic telephone switching designs as well as for automatic message retransmission systems for the telegram and telex services.

Magnetic drums were also used in most of the computers built in continental Europe between 1954 and 1961 [1]:

- in France: – for the first French-built computer, the "Calculateur universal binaire de l'armement" (CUBA), designed by Ingénieur général Nicolau and operational in 1952; – for the SEA I (1955) and SEA II (1960) machines designed for the Société d'Electronique et d'automatisme (SEA) by F.H. Raymond and derived from the CUBA; - and, lastly, in the so-called GAMMA (GAMMA I in 1956 and GAMMA II in 1960) machines, contemporaries of the SEA series, a commercial success of the Société des Machines Bull which sold many such computers in France and elsewhere in Europe [1, p. 184];
- in Germany where studies of magnetic drums started very early at the University of Göttingen (two successive drum constructions, the first in 1947 and the other in 1949); for the first Zuse machine in 1956 and the second in 1958 and in the computers built by telecommunication companies such as Siemens and Halske (1957) and Standard Elektrik Lorenz (1959); and in a computer designed at the Institute of Dresden (GDR) [1, p. 238, p. 152];
- in the Netherlands for the ARRA machine designed by Prof. Van Wijngaarden (1954) at the Mathematical Centre of the University of Amsterdam, and for Philips' Pascal machine in 1956 [1, p. 155, p. 158];
- in Belgium for the IRSIA machine designed by Prof. Belevitch and manufactured by the Bell Telephone Manufacturing Co. of Antwerp (BTM), another operator in the telecommunications sector [1, p. 160];
- in Sweden for the FACIT machine (1957) and in Denmark for a computer built at the University of Copenhagen;
- in Switzerland, for the EPF (Ecole Polytechnique Fédérale) machine in Zurich (1955) [1, p. 163];
- in Italy for a machine produced at the University of Pisa in 1960 and for the Olivetti 9003 computer (1960);
- in Austria for the machine designed by Prof. H. Zemanek at the University of Vienna;
- in Czechoslovakia for the SAPO machine (1958) designed by Prof. Svoboda at the Research Institute of Mathematical Machines in Prague;
- in Poland, for the ZAM machine of the Warsaw University [1, p. 163];
- in the USSR, for the first Soviet computer (the BESM, 1953) designed by Prof. S.A. Lebedev of the Academy of Sciences in Moscow; thereafter, for the M20 machine built in 1956, several successive versions of which were used in the first studies for the conquest of space; and, lastly, for the URAL machines (1954) which were mass-produced in several successive versions (from I to IV) as a result of the work of B.J. Ramezhev and J.J. Vassilevski.

In the middle of the 1950s, the computer industry in Japan was still in its infancy. Among the different electronic tube computers made at the time (particularly by NTT, NEC and Hitachi), one, the Tokyo University Computer (TAC) built in 1956, included a drum memory [1, p. 163]

4.5. Shift in advance technology from universities to industry in the 1950s

The end of the 1950s marks a decisive turning point in the general approach to the manufacture of electronic computers:

- From the technology standpoint, it marked the end of the first computer generation based on vacuum tubes and the beginning of the second generation based on transistors.
- From an economic and financial angle, the change was just as radical. A new industry was born. An American report of 1956 mentions the existence in that year of about 500 installed computers in the United States. Major companies competed for a foothold in a potential market which had become recognized as extremely promising. Among the foremost of these companies in the United States were those known as the "top five": IBM, Sperry Rand, Burroughs, Honeywell and NCR, followed by a dozen smaller companies.

After a short lag of a few years, the same change occurred in Europe and very soon afterwards in Japan.

Electronic machines ceased to be the fruit of the labors of university dons, scrapping together the necessary resources to give shape to their ideas. One after another, innovations in the computer industry began to emerge instead from the research laboratories of powerful companies.

The long enumeration in the previous section of the different uses of the magnetic drum is very representative of this changing trend.

Magnetic drums were marvelous instruments for laboratory research. They could be obtained from specialized manufacturers. They were not particularly expensive and they took up very little room. Later, seeing that they continued to be used, some referred to them pejoratively as "toys" for researchers suffering from arrested development, though the criticism was as harsh as it was unfair.

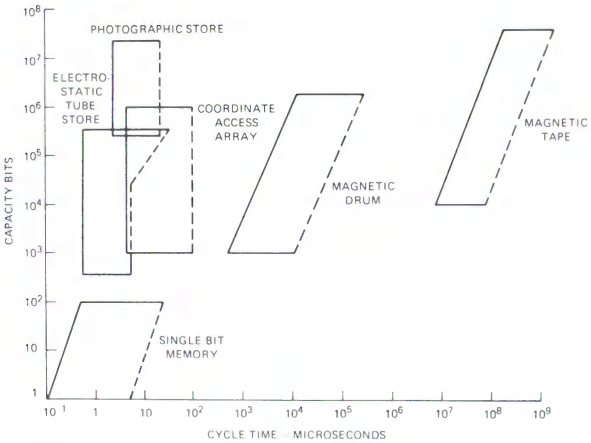

Fig. 4. Comparison of memory technologies: speed versus capacity

4.6. Use of drums outside the computer industry

Fig. 4 provides an excellent graphic representation of the comparative merits of the various types of memory available in 1956. This figure [7, p. 238] shows a review made at the end of 1956 (i.e. before the appearance of ferrite core memories) of the types of memory considered by Bell Laboratories engineers for their prototype electronic switching system (which was to lead in 1960 to the experimental Morris exchange). They finally chose an electrostatic cathode-type memory, the "flying-spot store", as a random access memory which combined a large storage capacity and a sufficiently short access time. The magnetic drum had been seriously considered, however, as a possible choice.

Although after 1965 magnetic drums were considered too obsolete for use as memories for electronic computers, they were still used very extensively elsewhere (unlike the delay line memories referred to earlier). They were particularly popular whenever a large storage capacity was required without any special access time constraint. Such cases included devices for automatic telegraph and telex message retransmission, air traffic control stock market quotations and airline seat reservations.

In telephone services, drums were often used in voice announcement devices, especially in interception positions. When it was decided to introduce automatic trunk dialing (DDD or direct distance dialing) in the United States, Bell Laboratories had to produce devices to operate for routing purposes highly complex translations of prefix codes of a dialed number. In the early 1950s, magnetic drums competed with other methods, but they were finally abandoned in favor of a device known as the "card translator" [7].

5. Ferrite core memories

5.1. The magnetic properties (especially the "magnetic permeability") of bodies used as cores to concentrate magnetic lines of force in inductance coils or transformers had always been a favorite subject of research laboratories in the telecommunications industry. A considerable amount of effort was devoted to the quest for increasingly efficient magnetic materials, whether for loading coils for long-distance cables or to produce filters for carrier systems.

The aim had been to avoid the eddy currents of magnetic lines of force. To achieve this, first of all a finely laminated core had been used, then a very close agglomerate, obtained under high pressure, of extremely fine grains of powder of a magnetic material.

In the Netherlands, the main research effort of Philips had gone into studying the ultrafine structure of crystals made up of different iron oxide combinations. This research, based on applying the theories of quantum mechanics to the study of phenomena referred to as "ferromagnetism [8]", led in 1943 to the discovery of what came to be known as "ferrites".

5.2. Ferrites are iron oxide combinations with ions of a bivalent metal, such as manganese,

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[7] see Volume I, pp. 396–397.

[8] This type of research is linked to the names of Hiltel in Germany, Snoek in the Netherlands and Neel in France, and led to the award of Nobel Prizes.

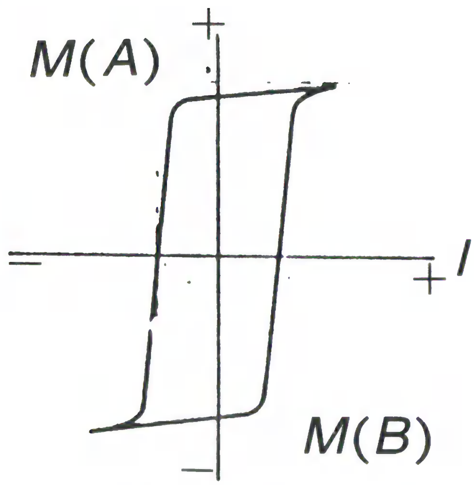

Fig. 5. Hysteresis loop of a ferrite

magnesium, copper or zinc (whose ions are comparable in size to those of iron). The cubic crystalline structure of these ferrites is similar to that of a natural ore, magnesium aluminate, better known as "spinel", a name which came to be quite often used in connection with ferrites, their appellation and their structural characteristics [11]. Among all the uses of ferrites, the most successful was that of a particular type of ferrite with hysteresis characteristics in the unusual form of a diagram representing an almost perfect rectangle (Fig. 5).

5.3. Ferrites with these characteristics [9)] were used from 1950 onwards (another invention at the MIT of Jay Forrester, mentioned earlier) in the form of tiny wire-threaded toroidal rings. A current I passing through the wire determines the magnetization M of the core, with the possibility of shifting it from a stable state $M(A)$ to another stable state $M(B)$. This produces a bistable binary state effect. If two wires instead of one are used in each core, one for writing and the other for reading, a large number of such rings constitutes a memory.

5.4. This type of ferrite core memory had an access time of the order of 10 microseconds, less than that of cathode tube memories. Used for the first time in 1949 for a high performance American "machine", the Whirlwind, commissioned from MIT by the Department of Defense, ferrite cores of the same design were copied and very widely used for computer memories in the 1950s, in the United States, on the 1953 UNIVAC 1003 model, the 1954 IBM 704, etc., as well as in other countries, such as France, the United Kingdom and the USSR:

"The magnetic core memory became the dominant memory in business and scientific computer systems. Coincident-current access techniques, with wires threaded through the cores, allowed the design of memories for which the size and cost grow as the square root of the total size of the memory." [4, p. 243] .

5.5. It comes as no surprise, then, to find magnetic core memories in the 1960s appearing as components of electronic switching equipment. Bell Laboratories used them for temporary memories to record the sequence of events making up a call, initially in the design of their PBX system ESS No. 101, then in the ESS No. 1 and ESS No. 2. Batch fabrication of "ferrite sheet" memory [10)] was developed by Western Electric to avoid manually assembling and threading of matrices of magnetic cores.

[9)] Apart from their specific use as a constituent of memory cores (an application which has now gone out of favor and is considered to be obsolete), ferrites have had, still have and will have many other types of use. These included in the 1970s their use as components of "Ferreeds" (relays making up the connection matrices of space technology SPC exchanges), and their use, still prevalent today, in the magnetic circuitry of high frequency inductance coils.

[10)] The ferrite sheet memory was first proposed by R.H. Meinken, then at RCA Laboratories [12].

6. A status of memory development at the end-1950s

A 1957 article by Goudet on the on-going studies in electronic switching [12] gives us a Table showing comparative costs of the various information storage methods of this period, a little before the appearance of solid state memories using integrated circuits. Advances in memory technology in the 1960s will be decisive to allow the birth of time-division switching using PCM and no more PAM method.

Goudet's Table
1957 Comparative Cost of Information Storage Methods

Access Time	Components	Cost per Bit in Dollars
Arbitrary Access at Great Speed	Ferrite Cores	1
(10^{-8} Second)	Cathode-Ray Tubes (with Associated Circuits)	1
	Vacuum Tubes	10
Access at Medium Speed (10^{-2} Second)	Magnetic Drum	0.01
Slow Access (10 Seconds)	Magnetic Tape	0.0001

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CHAPTER III-4

PROGRAMMING LANGUAGES [1,2,3]

1. Initial stages of programming

1.1. Computer programming languages have an entire history of their own, which, although scarcely more than 30 years old in 1984, is an extremely complex one marked by:

- rapid developments in the use of the languages;
- high specialization of languages depending on their fields of application;
- correlatively, a proliferation of such languages involving a whole series of associations and relationships.

Programming languages came into their own in the early 1950s. By then they were no longer regarded simply as practices for transcribing the instructions to be fed into the computer and entering the data to be processed. Programming was to become a skill, then an independent technical discipline and, eventually, a subject of studying and a science in its own right.

1.2. When the computer industry started just prior to 1950, the programmer acted virtually as a craftsman [1] with only the most elementary means at his disposal. His first task was often merely to encode binary instructions for teleprinters. "The ends of an instruction tape were glued together to form a paper loop ..." (John Backus, describing in [4] programming in 1948–1952 on the American SSEC (Selective Sequence Electronic Calculator) IBM Computer. Since these operations were finicky and tiresome, the need soon arose for equipment that would enable instructions written in intelligible languages consisting of letters and figures to be translated into machine language, i.e. into binary code. Program libraries were also quick to appear, offering subroutine programs for defining all the operations that the machine had to perform in carrying out a given phase of calculation, whether for simple arithmetical or algebraic operations or for classifying numbers and characters. Subroutine programs comprised ready written lines of program code for recurrent routines. Thus sections of a program could be written once, stored as a subroutine and then copied into a program whenever needed.

One of the first programming theoreticians was Professor Maurice V. Wilkes of Cambridge University in the United Kingdom (Fig. 1). As he states in [5], in 1948–1949 "experience of running programs on a stored-program computer was non-existent" and the approach to programming at the time was comparable to "gazing into a crystal ball". It was Wilkes who spurred the introduction of a consistent programming system based on "nested subroutines".

1.3. Until the early 1950s, the few electronic computer centers that existed, most of them at universities, operated independently and there

[1] Among the first people to write programs for electronic computers were top scientists in the Los Alamos Nuclear Physics Center (some of whom later became Nobel prize-winners in physics, e.g. Bethe), who did not hesitate to perform their own programming operations in their scientific computations.

Fig. 1. Professor Maurice V. Wilkes

was no interchange of programming procedures. Nor was there any literature on programming: certainly no specialized technical reviews in that field. When those in charge of computer centers started getting together in the United States, they simply had no idea of the studies that had been conducted on the subject in Europe, particularly by K. Zuse (Plankalkul, 1945) in Germany and H. Rutishauer (1952) in Switzerland [6]. It was only when computers entered the industrial production phase and ceased to be treated as laboratory items that programming languages began to spread. In fact, the success of certain languages was to depend essentially on the number of machines on which they were used.

1.4. Initially, the progress of programming languages was difficult owing to the limitations imposed at the time by the equipment on which the languages had to be used. Offering the programmer facilities for controlling – in a readily intelligible language – the operations to be performed by the computer had the drawback of considerably slowing down the speed of operation, particularly since the memories then available had very small storage capacity. The classic example of an extremely frequent programming operation which produced such an effect was the one which required a subroutine for expressing a "floating point" number (expressing a decimal number as a function of what is known in logarithmic terminology as its mantissa and its characteristic, i.e. a multiplier expressed in powers of 10).

1.5. The drawbacks of slow operation of the programmers due to the need of the translation of their instructions became evident in the early 1950s. It was already observed that the payroll for programmers at electronic computer centers was as high as the cost of the computer itself. Between one-quarter and one-half of the programmer's time, moreover, was spent in debugging [2)], i.e. correcting programming errors [6].

Basically, therefore, economic considerations led to the development of the first programming languages, just as later they were to spark the boom in software studies and the appearance of veritable software "workshops" or even "industries". This factor is the one covered in Part VII on specific programming languages for switching equipment.

From the early 1950s onwards, programming languages began to proliferate at an ever faster rate. A highly characteristic overall view is offered by an excellent book [1] published in 1981, the cover of which shows a synoptic view of the different languages that came into being between 1952 and 1972. The diagrammatic synopsis reveals the conceptual interactions between the languages and is just like a map of the sky with the stars and constellations. Despite its documentary interest and particularly the purely aesthetic qualities that would have made it a magnificent

[2)] The term "debugging" came into being in the early days of computers. In correcting operating defects in the Harvard Mark I machine, an insect, a bug, was found to have infiltrated the imposing mass of wiring, relays and selector switches which made up this first computer. It was Grace Hopper, then in the uniform of the technical branch of the American Navy and, after Lady Ada Lovelace of Babbage's days (19th century), certainly among the first people to work as a programmer, who discovered the cause of the trouble and coined this term now so firmly rooted in technological language.

illustration opposite this page, the "language map" is so large and so intricate that reproduction would reduce its details to illegibility; the reader is therefore referred to [1].

Moreover this is hardly the place to describe in detail the development of the languages intended for the computer industry. Instead, we shall simply give a broad outline and briefly mention with their years of introduction, the main languages which became important and well-known as they came into widespread use. Most of them will be the ones used as a basis for the design of specific languages for SPC switching system programming.

2. The main programming languages of the 1955–1970 period

2.1. Preliminary remark

This period corresponds to a time when electronic switching by stored programm control (SPC) was still in its infancy. It was only in 1955 that W. Keister and W.A. Budlong of Bell Laboratories suggested the use of programming to control a telephone exchange, only in 1960 that an SPC central office was first demonstrated experimentally in a service field trial (the Morris, IL, central office), and not until 1965 that the AT&T ESS No. 1, the first SPC-type central office, was put into service at Succasunna (NJ).

The seeds of what was to become a major branch and an essential component of electronic switching technology, namely, exchange software and its high-level languages, must therefore be sought in the following developments of programming for the computer industry.

2.2. FORTRAN Language

FORTRAN (FORmula TRANslator) was the first "high-level language" to see the light of day. Its purpose was to afford a concise program formulation using mathematical notations. The first version was published in November 1954 following its development at the IBM Laboratories by a group headed by John Backus. Historians of programming languages have noted that some of the concepts used in FORTRAN had already been advanced by Laning and Zierler for programming the Whirlwind computer [3)] with an "algebraic compiler", and by Rutishauer of the Federal Polytechnic School in Zurich, but it appears that their ideas were unknown to Backus and his team. This clearly shows the still primitive level of the new discipline of programming at a time when there was little information exchange between specialists in the subject.

The particular interesting innovations of FORTRAN included:

- the "IF", or conditional statement;
- the famous "GOTO" conditional branching statement which later proved to be very controversial.

FORTRAN was regarded in its day as the scientific language par excellence and was used on several types of computers, and not only those produced by IBM. Several successive versions appeared (Fortran II in 1958, Fortran IV in 1962 and Fortran 77). It had, of course, several offsprings including the Automatic Programmed Tools (APT) language which was specially designed for machine-tool control applications.

Some writers have discerned a relationship between FORTRAN and BASIC (Beginners All Purpose Symbolic Instruction Code), a language whose simplicity was to make it extremely popular and long-lived. BASIC, the simplest of all languages, dates from 1965 and often is the first to be used by students as a teaching tool and by trainee programmers learning to operate their home computers.

[3)] The Whirlwind, a landmark in the history of computing, was constructed at MIT (MA) for the US Navy by a team led by J.W. Forrester. It was put into service in 1950. "A 16-bit parallel, single address, binary computer, it used electronic tubes and magnetic tape drum for auxiliary memory". Typical of the state of art of these years, WHIRLWIND occupied a two story building with the basement filled with power supply and the roof covered with air conditioning equipment to remove the heat generated by a power consumption of the order 150 kW [7, page 1457].

2.3. ALGOL

The development of FORTRAN between 1950 and 1954 was the finest possible demonstration of what could be performed at that time by a compiler, a feat which removed many existing misgivings about the possibility of using a high-level programming language. The approach to the design of Fortran had, in fact, been purely pragmatic and was to give way to a new one in the late 1950s, when theoreticians, mathematicians and logicians, set themselves to defining *in abstracto* what the characterisitics of an optimum programming language should be.

The first product of this theoretical approach was the ALGOL (ALGOrithmic Language) language. Its idea ws born in Europe, in a study group headed by F.L. Bauer of the University of Munich, perhaps out of a desire to compete with Fortran, which was strongly marked by its IBM origin. The initial group expanded fairly quickly and, through the Association for Computing Machinery (ACM), came to enjoy considerable American help, particularly from J. Backus, the father of FORTRAN. ALGOL came into being in 1958 and was eventually produced in several versions distinguished in name by their dates – ALGOL 58, ALGOL 60 and ALGOL 62 (more exactly, "ALGOL 60 Revised").

Several characteristics of ALGOL had considerable impact on the design of subsequent high-level languages. These included more particularly:

- block structuring, offering the possibility of organizing blocks according to hierarchical structure and isolating the names of the variables in program blocks. (This feature was repeated in the PL/1 and Pascal languages)
- the mode of notation for writing the language, e.g. featuring five "modes" for denoting values: bool (boolean), char (character), int (integer), real and format; and rules for constructing new modes from these five basic ones.

Here we find the origin of the famous BNF notation standard which has been conventionally used ever since. This notation is by now so classic that it is referred to simply by the initials BNF to the bewilderment of the uninitiated, and there are even programming specialists who do not know what the three letters stand for. Officially, BNF means Backus-Naur Form (and not Backus Normal Form as is sometimes wrongly claimed). It pays tribute to its authors, J. Backus of the United States and P. Naur of Denmark, both members of the ALGOL study group. Examples of some of the BNF notations which came to be used in the CHILL language (CCITT High-Level Programming Language), defined in 1980 by the CCIT as standard programming language for SPC switching equipment, include:

- angular brackets, i.e. < and > to denote a syntactic unit expressed in strings of symbols selected from among those accepted;
- definitions characterized by the following symbol: := .

2.4. COBOL

The COmmon Business Oriented Language (COBOL) appeared in 1960 and gave rise to a series of successive versions such as COBOL 61, 65, 68 and 70. As its name suggests, it is a language essentially geared to management applications. It was initially developed to afford a high-level programming language for general application in data processing, one which would be valid for any of the computers on which it was to be used. Its most active promoter, and one at the origin of its development, was the US Department of Defense (DoD) which already had a considerable number of computers of different makes on which an equally large number of different programming languages were being used. The DoD naturally was anxious to achieve uniformity or even standardization of the languages. The same concern gave rise in the late 1970s to the ADA language, which also was developed to meet the specific requirements of the American DoD (see section 3.2).

2.5. The PL/1 Language [7]

2.5.1. The PL/1 language (Programming Language One) was developed at the IBM Laborato-

ries in the mid-1960s, to be used for both:

- scientific calculations (comprising few input data but algorithms requiring complex formulations and wide use of sub-routines involving numerous arithmetical or Boolean-logic operations)
- and business data processing (entailing the handling of considerable volumes of data, both at input and, in most cases, at output, and hence a large number of sorting operations, as opposed to few mathematical operations, except for those used for the most elementary arithmetical calculations).

This intrinsic separation between computer applications, which had led to a two-fold specialization of programming languages according to type of task, had existed until that time, but was already beginning to become blurred. Scientists had recognized the full value of computers in their work, and had introduced them into many areas of study, such as meteorology and elementary particle physics, for which a considerable volume of data also had to be processed and produced. Business management, for its part, was no longer content to use their computers only for issuing accounting balance-sheets or for stock control and payrolls: it required them to produce very elaborate statistics and, on the basis of these, tables of forecast data calling for highly sophisticated processing methods.

2.5.2. A committee consisting of users of the main computers of the time cooperated with IBM in developing the PL/1 language. Studies of this new language [4)] took into account the concepts which had been formalized by the main languages that had already been defined and were widely used, which were then FORTRAN, ALGOL and COBOL.

The PL/1, a synthesis of these languages, has a wider range of expression than any of them. Being more tightly structured, for instance following the principle of hierarchical structuring introduced by the COBOL language, but widening its use, the PL/1 has a greater capacity for reducing initial programming errors. On the other hand, it required programmers skilled in its use and the introduction of compilers with a large storage capacity. Being "hard to learn and hard to implement" [8], the PL/1 encountered some obstacles to its recognition and expansion. Together with ALGOL, it was one of the programming languages which, between 1965 and 1975, served as a more or less direct basis for those more specifically prepared for the software of switching operations, particularly the PAPE language which was developed in France [9] by CNET, the telecommunications research body, and which is derived from the PL/1 (see Chapter VII-1).

2.6. Other languages which emerged in 1960–1970

2.6.1. We shall only mention as a reminder such various languages as:

- APL (A Programming Language), developed in 1962 and remarkable for the introduction of the handling of data presented in arrays, and not only in strings of alphanumeric characters;
- so-called simulation languages, i.e., designed for simulation by computer processing of the model of a physical or logical system, particularly a system in which events occur in isolation (discrete-event simulation).
  Some of these simulation languages are:
  - SIMSCRIPT, derived from FORTRAN, which was developed by the Rand Corporation in 1963 and was "one of the first discrete-event simulation languages";
  - SIMULA, of Norwegian origin (Norwegian Computing Center) which was a 1965 offshoot of ALGOL and introduced the notion of data "classes", associated with the concept of a physical object, here called a "software object": this is designed on the basis of predefined types of data which are associated with a set of operations authorized only for the object. This method, with the limitations it imposes, results in what is known as the "encapsulation" of the object, or, in simpler terms, turns the object into a real "black box" in relation to

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4) The name of this new language was originally to have been the New Programming Language (NPL), but the British National Physical Laboratory (better known by its initials NPL), which was also very closely involved in computer programming, objected to this acronym – hence the adoption of another title, the PL/1. The main reason for citing this anecdotal fact is to show that the consultations leading to the development of the PL/1 extended beyond the United States [2, p.177].

the rest of the program. This concept will be widely used in other contemporary or later languages, especially those to be used for the programming of switching, such as CHILL. It is characteristic of what will be called a "strongly typed" language.

- GPSS, developed by IBM in 1969, which was one of the first languages with strong block structuring.
- and, finally, a switching network simulation language, developed at Bell Laboratories in the early 1960s and called "NEASIM".

2.6.2. As one of the oldest of the high-level programming languages, the LISP language also deserves special mention here. Developed by John McCarthy at MIT (MA) in 1959, LISP (LISt Processing) is entirely different from its contemporaries in that both programs and data are structured in the form of lists and there is only one kind of basic instruction, namely, a function call. In essence, therefore, LISP is based on a manipulation of functions. The writing of the language is thus quite specific and makes systematic use of multiple parentheses written within each other, which makes the reading of a LISP program extremely disconcerting for the uninitiated.

The use of LISP was to undergo a whole series of developments in the course of time. Little known in its early days, it attracted growing interest until nowadays it is regarded as one of the key languages, or, rather, as a mother language of those envisaged for tackling the thorny problems of "artificial intelligence". These include PROLOG, which initially was developed at the University of Marseille in France, and recently attracted attention as a result of research work on artificial intelligence carried out from 1980 in Japan.

It is to LISP that we owe the introduction of figurative descriptions likely to delight any ecologist – based, for example, on the concepts of trees, branches and leaves. Such expressions appear with increasing frequency in the explanations given in technical literature, including those related to the "environment" in which SPC exchanges and communication systems and networks have to operate. Perhaps they will eventually lead to the formalization in programming vocabulary of very simple terms used with an additional meaning different from their usual one (a very classical process in mathematics, as the so-called "Bourbaki School" language witnesses).

2.7. *Structured programming*

The late 1960s and the early 1970s witnessed a clearly-defined development in computer software. This period was marked by a critical analysis of the current high level programming languages and, above all, of the manner in which they were used.

Until then, stress had been laid on software efficiency designed to reduce storage capacity and computer operating time [5]. The period referred to above saw a shift in trends of the requirements of software design. The emergence of ferrite core and, later, integrated circuit logic memories, offering a higher capacity and greater speed of access, had the effect of reducing the importance of the above-mentioned two constraints. Four factors of major significance for software from then on were to be:

- increased programmers' efficiency
- reliability of programs;
- their readability;
- possibility of subsequent action on parts of the software, either to increase its dimensions or to introduce changes in them, i.e. what would be called from this time "software maintainability".

Larger and more complex programs had been appearing. The complexity of software was, moreover, increasing in non-linear fashion with the importance of the software. The quality of software was becoming a major concern. All this

[5] These were the essential and absolutely predominant requirements in the software of SPC exchanges (typically for the "call processing" function). In addition to the two requirements of rapid execution of instructions and minimum memory occupancy, there was the fact that the software designed for an SPC exchange was closely dependent on hardware constraints.

The above-mentioned shift in trends of requirements for software was thus to become evident only much later in SPC exchanges, let us say, in the early 1980s. It largely coincided with the 1980 emergence of the switching high-level languages.

demanded the introduction of well-structured programs which allowed different people to work on a single program, and whereby a program could be made easily intelligible when it had to pass through many different hands in a software production workshop. It was even more necessary in debugging operations, entailing consultation of interminable lists of complex, hard to decipher, highly imbricated instructions for which it was not always clear where blocks of conditional instructions began and ended.

E.W. Dijkstra of the Netherlands was among the first to emphasize the need for well-structured programming in a famous article in the form of a letter published in March 1968 in the Preceedings of the ACM (Association for Computing Machinery) under the title "GOTO Statement Considered Harmful". In this letter, he denounced the current abuse of the instruction GOTO, derived from FORTRAN, the unduly frequent use of which led to a tangle of instructions opening the door to a large number of programming errors. The article was followed by a whole series of theoretical papers proving that it was in fact possible to write a program using only three key structures:

- a sequential operational structure: unless otherwise stated, the instructions are carried out in the order in which they are written;
- the "IF-THEN-ELSE" selective structure which, combined with instructions BEGIN and END, should clearly mark the limits of a subprogram;
- an iterative DO-WHILE (or DO-UNTIL) structure engendering a repetition of instructions forming a well-defined whole.

Structured programming and "strongly typed" software (i.e., in which the "classes" or "modes" assigned to objects determine the operations that are valid for the handling of their data) thus became key terms in the design of the post-1975 high-level languages.

2.8. University studies concurrent with programming theory

The advent of the first computers aroused great interest in university circles, and even enthusiasm among certain researchers, some of whom already discerned applications far in advance of the most usual ones. These applications took many forms:

- Inspired by the ideas of J. von Neumann and N. Wiener, physiologists became fascinated by studies of the brain and the nervous system, the structures of which they were prepared to compare to those of an electronic system with a computer and a communication network. The initial enthusiasm in this field nevertheless faded rather quickly. It was not until many years later, as a result of information theory studies on and research into artificial intelligence and man/machine relations, and when more powerful computers became available, that this type of study regained a new impetus.
- Linguists discovered in the new science of programming methods a way of carrying out much more detailed analyses of language structure. On the basis of linguistic studies conducted for over a century, a new school of linguistic specialists was established, with Noam Chomsky as one of its most eminent representatives. Since the 1950s, the use of computers has been envisaged for the machine translation of written texts. An echo of this may be found in 1960 in an article [10] in the Telecommunication Journal (published by the ITU), that described the advances so far made in such research. Research into the recognition of the spoken language also began to take shape during that period. Some engineers of those days dreamed of the time when the international telephone service could be accompanied, for the greater convenience of users, by an automatic device translating the words of the speaker into another language heard by the listening correspondent. Twenty-five years later, in 1984, this field of research has again become highly topical and is now one of the priority objectives set by the highest telecommunication authorities of Japan [11]. A fact which, for the purposes of the technological history covered by this book, is more important than all these still distant prospects is that the theory of the structural analysis of

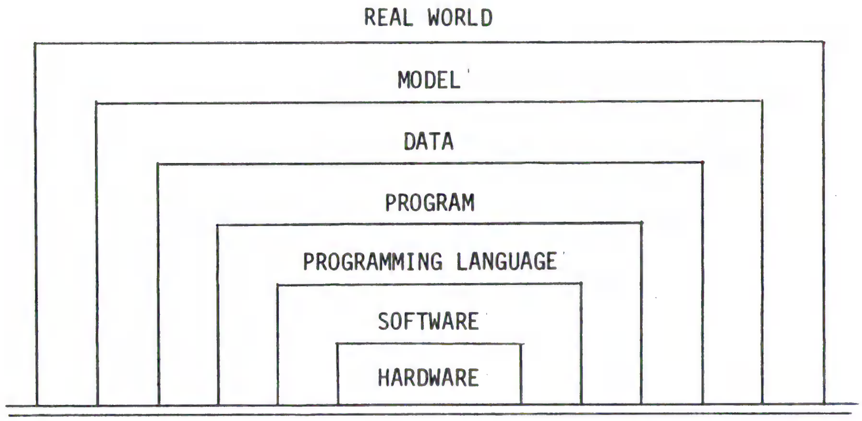

Fig. 2. A 1971 philosophical representation symbolizing the different abstract levels to be considered in developing a computer-controlled "system" [12].

natural language – essentially in written form – has undoubtedly influenced the design of high-level programming languages (quite apart from certain programming languages specially constructed for the purpose of analyzing natural language).

– In this connection, the analyses of the linguists correspond to those of logicians and specialists in related branches of philosophy [12], who found extremely useful aids in information theory and in the concepts derived from programming. Following in direct line studies carried out at the beginning of this century by B. Russell (United Kingdom) and in the 1920s by L. Wittgenstein (Austria) [13], the studies of this new school of logicians and philosophers influenced work and research relating to new programming languages. We can also discern in them the seeds of the concept of a communications system model stratified in successive layers (see for instance Fig. 2 extracted from a 1971 article of H. Zemanek). It was upon such a concept that, in the late 1970s, the ISO (International Standards Organization) developed and standardized its OSI (Open System Interconnection) model of communication systems, a model later adopted by the CCITT and a foundation stone for its studies and international protocols for data transmission, signaling and ISDN.

3. Main programming languages and their concepts in the 1970s

3.1. The Pascal Language

The Pascal language made its appearance in 1971 [14]. Designed by Niklaus Wirth, Professor of Computing Science at the Zurich Federal Polytechnic School, it was originally intended for teaching high-level programming. The name Pascal, unlike those of other languages, is not an acronym, but a dedication to the famous 17th century French mathematician and philosopher. In itself, this fact attests to the academism and scientific rigour which governed the development of the Pascal language.

The specification of Pascal was designed in the most formal manner and took account of all the concepts then applied to structured programming. Although originally intended for teaching, Pascal is by no means an elementary language. It is a highly developed language and it was designed from the outset to be used on large computers and for large programs.

One of the objectives of Pascal was to enable programmers to detect coding errors rapidly. For every symbol appearing in the program, the programmer must state in advance in the definition of these symbols the manner in which they can be used. Pascal is thus a "strongly typed" or, more accurately, a "strictly typed" language.

Before drawing up the specifications for Pascal, Wirth conducted studies on a version (ALGOL W, W for Wirth) of ALGOL, and there is a certain line of descent from ALGOL to Pascal. (Programs drawn up in ALGOL can fairly easily be translated into Pascal.) Being better structured than ALGOL and having the advantage of definitions of new sets of data types, Pascal was described as "an elegant, concise and disciplined language". Owing to these merits, Pascal language was to become most important, both in its use and its influence, which extended, inter alia, to the design of the CCITT CHILL language and of the ADA language of the United States Department of Defense (DoD). A sub-set of Pascal (GTD-5 language) was later employed as the programming language for the GTD-5EAX type of SPC exchanges of General Telephone and Electronics (GTE). A similar derivative of Pascal is also used in the programming part of the Northern Telecom DMS family (see Chapters VIII-8 and IX-4).

Due to and in addition to the qualities mentioned above, Pascal has the advantage of portability, i.e. it can be used on a large number of computers of different origins. This, together with the fact that it was not a company product, has prompted its widespread adoption.

In its applications Pascal has naturally gone through a whole series of successive versions or, more strictly speaking, "dialects" but these dialects may be said to take the form of grafts complementary to the actual level of definition of Pascal and have not affected its basic structural design. Wirth was the first to develop a new language, called the MODULA II, of the Pascal type, but even more sophisticated and intended both for high-level teaching and for advanced research. He is also a leading advocate of the principle that programming languages and software should not be designed for adjustment to their supporting hardware: rather the opposite concept should be adopted, i.e. the design of hardware and computers should be suited to the software to be used.

3.2. ADA language

3.2.1. As we shall see when discussing the CCITT CHILL language for programming SPC exchanges (see Part VII on SPC exchange software), the ADA language – more or less a contemporary of CHILL, though somewhat younger – was also born after long gestation during the second half of the 1970s.

ADA is the outcome of studies conducted by the United States Department of Defense (DoD) which was determined that one and the same language should be used for the wide variety of computers it owned. The DoD was and probably still is the world's biggest software consumer: "annual expenditure on software estimated (in 1982) at US$ 3 billion, more than 2,000 different types of machine on which over 400 languages and dialects were used ..." [15].

The DoD started its studies in 1975 but it was not until May 1979 that it finally chose, from among the latest versions offered, one proposed by a Honeywell-Bull team led by J. Ichbiah and made up chiefly of European programming experts. Like Pascal, the new language was given not an acronym but a name paying tribute to Lady Augusta ADA, daughter of the poet Byron, who worked with Charles Babbage in the 19th century and was the first programmer of all time. It took several more years to assess the ADA language, for which formal specifications were finally adopted only towards the end of 1983.

3.2.2. Like CHILL, ADA is a descendant of Pascal and a product of the predominant technology of the 1970s: consequently, it is a perfectly structured language with the mechanism that enables the different subprograms to be modularized.

ADA appeared, however, at a time when programming technology was beginning to develop rapidly with the new facilities offered to programmers by the introduction of new work tools

(e.g. the generalized use of consoles permitting program components to be presented visually and graphically on a cathode-ray screen, on which the program can be written directly). In the technological developments of the 1970s, the idea of distributed control systems – in which calculations are distributed between separate processors that exchange messages – was only in its infancy and consequently was not one of the priority objectives when ADA was being developed [16].

3.2.3. As in the case of the other high-level languages today, the name ADA does not denote only the specification of a language. It also implies a whole ADA software environment comprising:

- a broad range of tools consistently integrated in software workshops;
- a methodology for producing algorithms, concepts and techniques that can immediately be reused to provide appropriate solutions to new problems.

In the case of ADA, this software environment was implemented between 1978 and 1983 by the DoD and gave rise to successive specifications of it [specifications called Stoneman, followed by Methodman and STARS (Software Technology for Adaptable, Reliable Systems)].

4. Software engineering [16,17,18]

4.1. Large-scale software construction embraces a whole series of operations.

The approach is top-down, proceeding from the general to the particular, with an increasing hierarchy of complex operations and abstractions.

To design a system, its functions – "its specifications" – are usually first described in natural language. To avoid the ambiguities of a natural language, the concepts defined in this first written specification must be translated into formalized writing, i.e. a specification language based on diagrams (e.g. "State Transition Diagrams") and clearly showing all possible imbrications and bifurcations that can occur in the program.

The next stage is the programming itself. This is a translation process, converting the computer related part of the specification into a language intelligible to the computer. This will generally be in a high-level language to be translated into computer language or an assembly language, by means of a compiler. Programs will as a rule be subject to a stepwise decomposition and partitioned into modular software components. With inter-module interfaces carefully specified, the modules should be (relatively) independent, making them easier to code, test and later to modify. The modules will have, only in the end, to be connnected to each other by linkage editors.

The last stage consists of program verification and validation. Since it will be carried out first for each of the modular sub-units comprising the program, and then for the program as a whole, a bottom-up operation will be in order for these phases of verification and validation.

4.2. Since the early 1970s, the production of software for complex systems has comprised a special branch of engineering, known as "software engineering", a term coined in 1968. Its importance is demonstrated, *inter alia*, by the fact that an international telecommunication conference, the International Conference on Software Engineering, is now held on the subject every year (the seventh being held in 1984).

Software engineering has often, and quite rightly, been termed capital-intensive since it requires a whole set of costly data processing and computer equipment comprising, around a central computer:

- a sophisticated data-base management system, e.g. for filing and managing all the items, programs and subprograms utilized in the life of a system;
- individual programmer work stations, each with access to the central computer, which provide programmers with a universal tool for producing software items, acquiring documentation and exchanging messages;
- for the last-named purpose, systems for communication between work stations and mainframe computers;
- compilers, text editors, etc.

All this calls for a heavy investment which nevertheless is fully warranted by the improvements that result in terms of both programmer productivity and reduced debugging operations.

4.3. The steady reduction of software errors is a constant struggle for a programming manager of a company developing systems in which software plays a large part, so that high priority is now being given to the development of systems for ensuring that programs are bug-free. Besides all the arrangements made for organizing software workshops and maintaining strict discipline based on a consistent methodology, and besides the use of "strongly typed" languages, active research has been going on since the early 1980s into ways of automatically verifying and even proving that programs are error-free. Different methods are envisaged, some based on mathematical (algebraic) language structures, others on axiomatic principles or on the graphs of PETRI networks theories.

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CHAPTER III-5

A SHORT SURVEY OF THE COMPUTER INDUSTRY AFTER 1960. INTERRELATIONSHIP BETWEEN COMPUTERS AND TELECOMMUNICATIONS [1,2]

1. The 1960s

1.1. Generations of computers succeeded each other in turn. The second generation is placed by specialists as dating from the early 1960s: after 1962, often cited as the year of change, computers were no longer fitted with tubes but instead were fully transistorized and their magnetic-drum memories were replaced by ferrite cores [1].

The computer performances were spectacularly increased as regards both speed of calculation and reliability. Prices also fell in terms of the quality of service offered.

In those years computers spread at an impressive rate even if most of those in operation were still American at the time. Moreau [1a] estimates the total number in operation in the Western world in early 1964 at 20,000, 80% of them in the United States.

1.2. Computers were no longer simply instruments confined to university laboratories or scientific calculation centres. Nor were they used exclusively for elaborate ballistics, astronomic or nuclear physics calculations, although they were still constantly used in connection with military applications. Indeed, the United States Department of Defense was a great computer consumer; for instance, some of its systems such as the Semi-Automatic Ground Environment System (SAGE), set up in the 1950s to protect United States air space, witnessed the introduction of innovations which proved of the utmost importance as regards their spin-off into other fields. However, from 1960 onwards, computers started to become mainly management tools with every major business office computerizing itself. For reasons of efficiency in the name of which excesses were sometimes committed, and sometimes even for simple reasons of a company's prestige of brand image, the computer had become fashionable among the leading corporations.

1.3. The investment required for producing computers had also risen sharply and machines of this or that model had to be sold in large numbers in order to recoup the sums invested in their design. The operating system of the IBM 360 which came out in 1964 took 5000 man/years simply to design [1b]. More than 1600 IBM 650s were marketed from 1954 onwards [1c] and some years later IBM produced over 10,000 units of the 1401 model launched in 1959 [1d]. Manufacturing computers, therefore, was and would remain the prerogative of powerful companies, led by IBM and followed by a large number of major companies engaged in electronics. A little later, a rash of new companies emerged in their wake to engage solely in the production of computers offering a specific range of uses (e.g. the Digital Equipment Corporation in 1962). These were generally set up by former employees of the larger coporations, full of bright ideas which they

[1] Ferrite cores appeared in 1954 and reigned supreme in the production of memories until the mid-1960s.

felt their employers failed to recognize. Having great drive, they soon found in the American financial environment the wherewithal to create industries that have become known all over the world.

1.4. It was also in the early 1960s that computer production put down strong roots in such places outside the United States as Japan, Europe (particularly in the United Kingdom and France) and the USSR.

1.5. The manufacturers of the second generation of computers initially offered machines specializing in such applications as scientific calculation or, on the other hand, repetitive management operations.

The first type, sometimes known as "number crunchers", required elaborate algorithms for handling them. It was the writing of these algorithms that gave rise to the increasingly developed programming languages, the "high-level" languages.

Those of the second type were insatiable absorbers of data which, after processing, they regurgitated onto countless sheets of paper moving at great speed and quickly forming stacks. The wealth of information thus churned out did not always facilitate selection of the information wanted [2)].

1.6. This dichotomy based on the intended use of the computer became blurred after the mid-1960s when there was a move towards machines for universal application. In turn, this universality permitted very long production series and some models, such as the IBM 360 launched onto the market in 1964 [3)], proved extremely successful.

[2)] According to Alvin Toffler, "The problem is not of information but of information overflow".

[3)] The serial number given to this IBM model was intended to suggest its numerous uses, recalling the 360 degrees used in the measurement of angles.

2. Computer input and output peripherals and their access modes

2.1. The advances made in the computer itself, i.e. in its central processing unit (CPU), were matched by progress in its input and output peripherals.

In the first generation these were generally punched-card processing equipment.

A wonderful description of the successive ways in which computers were used in the scientific environment of the 1950s and 1960s is given in "A History of Engineering and Science in the Bell System – Communication science" [2a] (see Box A). Here we see the emergence of inputs and outputs no longer in punched-card form but on magnetic tape.

2.2. Whether on punched cards or magnetic tape, the computer output had to be converted into paper form for easy reading by the user. After printers of the teletypewriter variety there appeared a whole series of fast and even high-speed printers which in their day (nowadays we are somewhat blasé) amazed the layman with their ability to print, say, fifty pages of text or tables per minute.

2.3. So far as the purposes of this book are concerned, however, it was largely the input peripherals giving access to the machine that brought about a radical change in the way computers are used.

2.3.1. It is in 1961 that Professor Corbato [3] of Massachusetts Institute of Technology (MIT) is said to have got his students to use a computer on a time-sharing basis. This required a secondary store to act as a buffer but, above all, a program management system.

2.3.2. The reader will note the coincidence in time between these arrangements at MIT and the work being done by Bell System engineers to develop the ESS No. 1 system, i.e. in the very early 1960s, following successful experiments with Morris's first SPC system. The scheduler used in the ESS No. 1 for sequencing different phases in

Box A

The Growth of computation in Bell Laboratories.
The beginnings (1950–1960)

With the advent of electronic computers in the commercial marketplace, Bell Labs engineers ceased to design machines for routine engineering, commercial, or scientific computation, but continued to be involved in the design of computers for special purposes, notably telephone switching.

In the early 1950s, more than 60 people were employed full time doing engineering calculations. These workers were usually female and well trained in mathematics but not engineering. When they began using computers, their classification changed from computress to the more esteemed title of programmer.

Through the 1950s, a succession of commercial computers went into use at Bell Labs. The IBM Card Programmed calculator (CPC) in 1952, the IBM 650 in 1955, the IBM 704 in 1958. An open shop for scientific computing, available to all comers, evolved around these machines.

For the IBM 650 serving Bell Labs scientists and engineers, the operating procedures were straightforward: a user's program and data were keypunched and proofread, then the card deck, preceded by an interpreter, was read into the computer, and the output appeared at the other end of the machine, also punched into cards. The output deck was then printed for the user on a tabulator.

When the main computer at Bell Labs was replaced by an IBM 704 in 1958 the monumental new language FORTRAN was to be the principal programming vehicle, but no effective way to run small jobs was available. This need was met by G.H. Mealy and D.J. Hansen, who constructed a computer operating system that would run jobs sequentially on-line or off-line, off-line input and output being mediated by magnetic tape. Neither the first nor the last operating system for the 704, the Mealy-Hansen system, known as the Bell Operating System (BESYS), was one of the more influential and longest-lived.

Under the Bell Labs operating system control, users seldom approached the machine, and the console operator had little to do but punch a time clock – computers did not then have their own – at the beginning and end of jobs, which typically lasted about a minute. By 1960, several hundred people were regularly involved in scientific computation. Though computing represented less than five percent of the company budget at that time, Hamming predicted that one day half the resources of Bell Labs would go into computers and people directly involved with them. Few listeners, if any, believed such hyperbole, but time proved him right some 20 years later.

the processing of large numbers of telephone calls is based on the same principle as that used by the MIT students in individually submitting their little exercise programs to the IBM machine. Yet the ESS No. 1 scheduler was subject to infinitely more severe constraints as regards the maximum time allowed for accepting a call processing phase and the number of calls likely to be handled within a given time span.

2.4. The use of time-sharing computers rapidly spread since they offered the double advantage of:

- making the utmost use of the entire calculation capacity of a large computer;
- and adapting the computers's high operating speed to the infinitely slower process of human operator intervention in the program sequences.

Time-sharing offered the possibilities of an open shop computing centre accessible to what were later to become known as "work stations". In those days these were usually teletypewriter terminals which had only one step to take however close or distant from the computer they were located. This was the beginning of data transmis-

sion and what was to become known after 1980 as "telematics" [4].

2.5. The development of an operating system for sequencing program segments from different users for processing by a time-sharing computer was a subject of major importance. "A history of Engineering and Science ..." [2c] tells us how Bell Laboratories were involved in 1964 in the preparation of such a system, known as MULTICS, which was studied jointly by Bell Laboratories, General Electric and MIT and how they eventually dissociated themselves from it in 1969. The same work also informs us how K. Thompson, a Bell Laboratories researcher working alone in a quiet corner with the help of a disused minuscule computer (a PDP-7), came up with an operating system far simpler and much more user-friendly than the MULTICS. He baptized his system "UNIX" in a reaction to the gigantism of MULTICS. The UNIX system quickly found enthusiastic supporters within and later outside Bell Laboratories and from the early 1980s onwards became the subject of widespread interest.

2.6. The use of a computer on a time-sharing basis was intended to serve users having their own individual programs; it was therefore aimed at professional programming experts.

Another use of computers, one related and sometimes wrongly confused with time-sharing, is the *on-line system*. Its users no longer have to be programming experts: they are ordinary employees who have absolutely no knowledge of computer techniques but do know how to operate a terminal keyboard for interrogating a computer and receiving its reply. The system was first implemented in 1963 under the SABRE project for reserving seats on American Airlines passenger flights [1e]. The project was a success and soon caught on among every other airline, followed by hotel chains and railways, etc.

The system was also introduced among banks (First National Bank of Chicago in 1962). Here we have the birth of remote management and this, of course, implied data communications and circuits constantly available to carry them.

3. Computers and telecommunications

3.1. The penetration of telecommunications into computers increased and was enhanced from the early 1960s onwards.

This was accompanied by reciprocal interaction in the development of their technologies, affecting such aspects as memories, integrated circuit components, programming languages and algorithms, including coding algorithms for detecting and correcting bit errors, etc. The most spectacular manifestation of this technological convergence was the birth of Western Electric's ESS No. 1, the first system with SPC switching.

3.2. Digitization, i.e. bit processing, became the common denominator of telecommunication and computer technology, although the two industries are very different in nature:

- telecommunications are generally monopolies managed by official Administrations or by private corporations tightly regulated by the government;
- whereas computers are the affair of industrial enterprises which have far more freedom of action, e.g. as regards the purely competitive establishment of their prices and the amortization time assigned to their equipment, which is infinitely shorter than that allowed for telecommunication equipment.

3.3. Yet despite the severe constraints imposed on the telecommunication industry, the intrinsic go-ahead nature of manufacture in the two sectors started nudging them both towards what some saw as mutual encroachment on what until

[4] Stibitz had foreshadowed and was, so to speak, the initiator for telematics when, in demonstrating his relay calculator (the "complex number" computer) in September 1940, he operated it over a standard long-distance teletypewriter circuit between a lecture room in Hanover, New Hampshire, and the Bell Laboratories Building on West Street in New York City [2b].

the early 1970s had been their traditionally separate fields.

In the 1970s the marriage between computers and telecommunications became a central theme of speakers in academic forums and writers in technical reviews. In the United States, where official regulation imposed strict segregation between the activities of carriers, even down to differentiating between the telephone and telegraph services, the Federal Communications Commission (FCC) had great difficulty in determining the fields in which it could authorize American carriers to operate. After all, what were data? They were, of course, telegraphic in nature but had to be routed over telephone circuits and converted for analog transmission by modems. How and to what extent could computers be used as turntables for retransmitting messages? To what extent could the information from received data be processed by a computer at the incoming end of a transmission line?

These almost inextricable problems provided the inexhaustible subject fo FCC inquiries and counter-inquiries and it was only after much effort and time that the Commission endeavoured in its Computer Inquiries I and II [5] to establish a clear-cut administrative frontier between the two fields, namely carriers and computers.

[5] The Computer Inquiries of the FCC were proceedings intended to determine to what extent common carriers could properly employ data processing technology in furnishing services. Computer Inquiry II decision (Docket No. FCC 20828), issued in December 1980, was considered as having far-reaching implications for the communications industry. The Decision distinguished between "basic" and "enhanced" services. The former are network services that simply transport information without any alteration. "Enhanced" services are those in which some aspect of the original information is changed or where customers interact with stored information. By this Decision, Bell System was authorized to offer services embodying data processing – what the FCC calls "enhanced" services – through separate subsidiary entities. (Another term in international usage for naming the "enhanced" services is "value-added" services.)

3.4. This is no place for considering the conceptual success of the FCC definitions. The general opinion among commentators was that the two fields had become so interwoven that any strict delimitation of activities was bound to be somewhat arbitrary and become increasingly blurred. The situation could hardly be better described than by the Canadian who asserted metaphorically that technology is like the waters of a major flood. However many dams were built to stem them, they filter through everywhere and will break through any artificial dam constructed in haste.

3.5. Less philosophical but far more pragmatic than the FCC's conceptual delimitations between fields of activity is the fundamental concept of the "*interface*", used by the CCITT as the body responsible for international standardization in telecommunications. This concept defines the responsibilities of the computer (or terminal) user and the telecommunications enterprise. The whole structure of the CCITT Recommendations rests on the interface concept and on the definition of the basic characteristics to be observed by both responsible partners on each side of the interface. Resorting to the interface concept is therefore standard practice in CCITT deliberations, not only for defining the frontiers (and attendant responsibilities) between telecommunication enterprises and those who use its messages [6], but also serving to define requirements within a telecommunication enterprise, e.g.

[6] The interfaces external to a telecommunication enterprise are, of course, defined in close consultation between the parties concerned. Within the CCITT's international deliberations, these consultations and discussions are conducted with the bodies which represent telecommunications message users, i.e. mainly the International Organization for Standardization (ISO) but also many other bodies such as the European Computer Manufacturing Association (ECMA) and its American and Japanese counterparts in the data communications field.

for specifying the conditions of access of a circuit to a switching centre.

Bibliography

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[2] HESBS *. Communications Sciences, (1925–1980), AT&T Bell Laboratories, 1984: 2a: pp. 367; 2b: pp. 358–359; 2c: pp. 371–372;
[3] F.J. Corbato et alia: An Experimental Time-sharing-System. Proc. American Information Processing, San Francisco Conference, 1962, pp. 335–344.

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* See the book's reference in General Bibliography of Part III, page 68.

Part IV

Semiconductors researches and Microelectronics Developments

CHAPTER IV-1

THE BACKGROUND HISTORY OF SEMICONDUCTORS

1. Semiconductors: how to define them. Their specific properties [1,2,3]

1.1. Electrical conductivity is one of the most characteristic parameters by which physicists until recently and traditionally classified materials, whether solids, liquids or gazes. [1]. This is primarily due to the very wide range of the conductivity of different materials. For materials normally encountered by the physicist [2], there are roughly 23 orders of magnitude (powers of ten) between the conductivity of the best conductor metals, such as copper, and that of some "usual" materials such as glass or crystals (e.g. alumina crystal), which have the lowest conductivity. To enable the layman to grasp more easily the magnitude of this range in values, a comparison is often made with linear distances – in this case it corresponds to the difference between one unit of length, i.e. a metre, and the distance of a star at 10 million light-years.

The importance of the conductivity of a material also stems from the fact that, particularly in the case of solids, there is a close relationship between conductivity and the other physical properties of the material.

[1] Whereas electricians, and in particular electrotechnicians, refer to the well-known concept of resistivity "ρ" ("rau"), physicists opt to refer to the conductivity "σ" ("sigma") which is simply the reciprocal of the resistivity: $\sigma = 1/\rho$.

[2] We are obliged to insert this restriction since with the progress of modern physics there are now supraconductive substances which at very low temperature offer an infinite conductivity (i.e. a zero resistivity).

1.2. By and large, it may be said that semi-conductors are solids, generally in a crystal form, characterized by a conductivity lying roughly in the middle of the range mentioned above.

There is an almost infinite variety of semi-conductors. Because of a natural wish to obtain the most useful results, technological progress and advanced research relating to the properties of different materials have been focussed on a relatively small group of these substances. Consequently the laypersons – and even the telecommunication engineers – take the term "semi-conductor" to apply to a small group of materials only: Germanium in the 1950s and since the 1960s essentially Silicon together with their compounds, plus some other similar materials. It is almost exclusively to these materials that we shall henceforth refer when explaining the behaviour of semi-conductors and their use in electronics. It must be made clear, however, that the limitation which is thus implied as to the scope of what are generally called "semi-conductors" is purely a matter of casual usage in technical and industrial talk [3] and is, strictly speaking, not really justified in physics.

The property of being a semi-conductor is not confined to pure elements such as Germanium or Silicon. Compounds and alloys of elements account for a greater proportion of semi-conductors, and they include many substances, such as

[3] We should also not forget the element Selenium in the list of semiconductors largely used in industrial applications, specially in telecommunications, e.g. for photocopy-type devices.

Gallium arsenide (GaAs), Indium arsenide (InAs) and the Indium-Antimony alloy (InSb), these last three being the subject of many references in the present technical litterature.

1.3. Looking back in history, it was semi-conducting materials other than Silicon or Germanium [4] which commenced and continued to fascinate scientists from the first half of the nineteenth century. There was a steady accumulation of observations on the physical and electrical properties of a number of those materials. Box A gives a few milestones which have acquired some value as historical references.

The main feature that distinguishes the behaviour of semi-conductors from that of metals relates – as their names imply – to electrical conductivity. Their conductivity can vary greatly:
- with the temperature of the material;
- with the degree of chemical purity of the material;
- in the case of some of these materials, under the influence of radiation (such as light, ultra-violet rays, or X-rays).

The discovery of these phenomena was only a first step: the next was to try to explain them. It took a long time – almost a century, in fact – to elaborate theories from which the results of calculations were more or less in agreement with the results of experimental observation. Before unveiling the mysteries of the behaviour of semi-conductors, theoretical research during the 1920s and 1930s concentrated first on attempting to interpret the less puzzling phenomena of conductivity in metals.

Box A

Milestones of the earliest experimental observations about the special properties of semi-conductors

1839 Antoine-César Becquerel (France), whose descendants included several famous French physicists, discovered the photoelectric phenomenon: an electromotive force is generated when light shines on the junction between an electrolyte and certain substances (the latter being semi-conductors, albeit, not yet called as such at that time);

1873 Willoughby Smith (United Kingdom) observed that, under the influence of light, major variations took place in the conductivity of Selenium;

1874 Ferdinand Braun (Germany) noted the "rectifying property" * of metallic points – the "cat's whisker" – in contact with Lead sulphide (PbS) in the form of a galena crystal;

1886 C.E. Fritts (United States) observed that Selenium had the same rectifying property.

* This rectifying property was associated with the first metal/semi-conductor junction to have been put to practical use, to provide the detector for the earliest radio-electric receivers. Those with memories of the 1920s will recall how popular the mysterious but inexpensive receiver known as the "crystal set" was with the young generation of that period.

[4] Germanium was not discovered until 1886 by the German chemist C. Winkler and its properties did not come to be widely studied until the 1920s, and in particular 1930.

2. The scientific basis for theoretical studies of electrical conduction through a solid

2.1. Attempts by physicists to understand the mechanism of electrical conduction through a solid date from the beginning of this century

The honour of having been the first to study this topic falls to the German physicist Paul Karl Drude (1863–1906), of Berlin. In 1900 he put forward the theory that current passing through a metal consists of a transfer of electrons – those electric particles which the renowned English physicist J.J. Thomson (United Kingdom, 1856–1940) had just shown (1897) to exist in rarefied gases [5)].

According to Drude's hypothesis, conductor metals contain inside the lattice of their atoms a cloud of free electrons. The velocity of these electrons is increased by the presence of an electrical field created by a pair of electrodes attached to the two ends of a metal conductor. Thus, an electrical charge is transferred from one electrode to the other – i.e. there is a flow of electrons, generally called a current – and hence details of the metal conductivity can be ascertained.

The above-mentioned flow and acceleration of the electrons is, however, restricted by collisions and scattering which they undergo on their path, simply because of the existence of the lattice of the atoms of the metal. In this way, the electrons acquire an average velocity – called their "drift velocity" – which is proportional to the electromotive force between the two electrodes.

The model conceived by Drude provided a satisfactory explanation for several experimental phenomena, well known at the time. There were, however, a number of contradictions between the results of calculations based on the accompanying theories, and other well known experimental phenomena, in particular the variation in the conductivity of a metal in function of the temperature.

2.2. More than a quarter of a century was to elapse before the evolution of the advanced theories of quantum mecanics enabled these discrepancies to be explained.

Each of the outstanding physicists of the present century (Fig. 1) is linked with the birth of this new branch of science, and of *solid state physics*. It was the latter which, after prolonged research and many hesitant steps, provided the basis for the theories of semi-conductors, leading to the invention of the transistor in 1947.

According to Professor Esaki [6)], solid-state physics, " which involves experimental investigation as well as theoretical understanding of the physical properties of solids, constitutes (in 1979), by a substantial margin, the largest branch of physics: probably a quarter of the total number of physicists in the world belongs to this branch" [4].

2.3. In the course of the history of technology, few have appreciated and recognised the legitimate scientific link between the refined products of today's electronic industry and all the theories on which modern physics are based (see however insert in Box B). All too often, and particularly on the part of the general public, these theories are considered to have led only to applications – military or peaceful – of nuclear energy, or to the research, as mysterious as costly, being carried out in the four or five main nuclear research centers devoted to researches of a pure scientific and fundamental character on sub-nuclear particles, existing in the world.

It is not the intention here to recite, even in outline, the entire history of the modern theories

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[5)] In the rarefied gas of a cathode ray tube, the deflection of a beam of the rays by an electrostatic force enabled J.J. Thomson to make the first known estimate of the mass and electrical charge ("e") of an electron. These values were obtained with greater accuracy (to within 0.1%) in 1916 in experiments carried out by R.A. Millikan (United States, 1868–1953), who was awarded a Nobel Prize in 1923.

In 1906, Sir J.J. Thomson received the Nobel Prize for his discovery of the electron.

[6)] Recipient of the Nobel Prize for physics, 1973.

Fig. 1. The great names of the modern physics (*inter alia*: Niels Bohr, Marie Curie, Albert Einstein, Werner Heisenberg, Max Planck, Erwin Schroedinger, etc.) attending a Brussels meeting at the Solvay Institute.

Box B

A quotation from Preface of "Sources for History of Quantum Physics" [5]

Nor are only physics and philosophy being transformed by quantum physics and related developments in theoretical physics. Rare today is a new product of the chemical industry which was not first formulated in terms of quantum orbitals. *No one can telephone today without using devices based upon the quantum principles.* Almost all the basic novelties in the field of metallurgy and magnetic materials originate in ideas that came from quantum theory.

of physics: suffice it to recall in Box C some of the famous names (see Fig. 1) and events which mark this history of science. The discoveries made during the first three decades of this century in that branch of theoretical physics – surely the most disinterested science of all –, followed by a fifteen-year "incubation" time, clearly laid the foundations for the tremendous advance which took place in modern electronics since the late 1940s.

2.4. In 1923, L. de Broglie brought about a radical modification of the theory of the behaviour of electrons (both within the atom and in a body made up of a multitude of atoms) with his proposition that to each electron in motion there corresponds a standing wave of fixed wavelength. The dual concept of an electron as both a particle and a wave was confirmed experimentally in 1927 by analysis of the diffraction of electrons by a crystalline structure (C.J. Davisson, United States, Bell Laboratories [7]), and its applications were extended to particles other than the electron. It was itself an extension of the dual concept, perceived in 1905 by Einstein, of photons as "grains" of light associated with the light wavelength.

This duality was to become a main basis for quantum mechanics and soon led to mathematical interpretation of Bohr's rules for quantization. In 1926, E. Schroedinger, with his "partial differential equation", determined the key mathematical relationship which defined the behaviour of a quantum particle in terms of wave functions. Expressed in terms of particle energies – and with the constraints of limit conditions – the only solutions of Schroedinger's equation are sets of discrete quantized energy levels. Thus, the energy of the system inside an atom cannot alter other than by strictly defined jumps: here we have the quanta.

The discrete succession of the levels of energy, which, corresponding to the solutions of Schroedinger's equation, are the only ones possible, represent the "quantum levels" of the atom. These levels form part of a fairly complex series which, from 1928–1930, were to be expressed by means of four sets of quantum numbers. [8]

2.5. In the beginning of the 1930's, Félix Bloch (Switzerland–USA), Léon Brillouin (France) and A. Joffe (U.R.S.S.) applied the theory of quanta to crystals to evaluate the action of electric fields on the electrons in the arrays of atoms of a crystal:

– first appearance of the *concept of "energy bands"*. The propagation of quantum-mechanical electrons through a regular crystal structure [9]

[7] Which awarded him the Nobel Physics Prize in 1927.

[8] The four quantum numbers are: (i) the principal number; (ii) the orbital (or azimuthal) number; (iii) the magnetic number; and (iv) the spin quantum number. Each is characterized by a letter (e.g. "s", "p", "d" and "f" for the orbital numbers). These letters are frequently shown on the diagrams of the "energy bands" of an element.

In 1924, in the Netherlands, G. Uhlenbeck and S.A. Goudsmit put forward the concept of "spin" – a fifth quantum number indicating an option taken as between two directions, parallel and anti-parallel, of the rotary movement of an electron.

[9] The X-ray diffraction discovered in 1912 and applied to the structures of solids by Lawrence Bragg provided physical measures of structures at atomic scales.

Box C

A brief summary of some famous names and discoveries in modern physics during the first three decades of the present century (references [3] and [6])

1900 Max Planck (Germany, 1858–1947), Nobel Prize, 1918, suggested the existence of quanta of energy;

1905 Albert Einstein (Germany, 1879–1945), whose other achievements had already brought him fame before the age of 30, put forward the notion that light is composed of individual quantas (later called "photons"), and gave an explanation for the photoelectric effect, i.e. for the emission of electrons when light shines onto certain solid bodies. *

1911 Rutherford (United Kingdom, 1871–1937), Nobel Prize for chemistry, 1908, proved that the atom has a core – called the "nucleus" – which has a concentrated positive charge, equivalent in magnitude to the negative charge of all the electrons at a distance from the core;

* It was this discovery – and not the discovery of relativity (the $E = mc^2$ relationship) which, also made in 1905 (special relativity) and extended in 1915 (general relativity), was still considered highly controversial – which in 1921 earned A. Einstein the Nobel Prize for physics.

Box C (continued)

1913 Niels Bohr (Denmark, 1885–1962), Nobel Prize, 1922, used quantum theory to develop his famous model of the atom, and showed that electrons are confined to certain orbits. Only when one or more electrons suddenly jump from one quantized orbit to another a change in the state of an atom takes place – hence Bohr's explanation of the regular pattern of emitted light (spectral series) from hydrogen atoms in a state of excitement;

1922 N. Bohr showed the relationship which exists between the chemical valency of a body and the number of electrons on the admissible orbit which is furthest from the nucleus;

1924 Louis de Broglie (France, 1895–1987), Nobel Prize, 1929, won acceptance of his novel theory of the dual concept of particles of matter – and especially of electrons – as both particles and elements of waves: every electron is accompanied by a standing wave, the frequency of which conforms to the quantum rules laid down for N. Bohr's model;

1924–1927 Paul Dirac (United Kingdom, 1902–, Nobel Prize 1933), Erwin Schroedinger (Austria, 1887–1961, Nobel Prize 1933), Werner Heisenberg (Germany, 1901–1976, Nobel Prize 1932) and Max Born (Germany, and subsequently United Kingdom, 1882–1970, Nobel Prize 1954) lay the foundations of quantum mechanics.

is a problem in diffraction theory. Due to interactions within the regular lattice structure of atoms in the crystal, the discrete sets of energy level of electrons in an isolated atomic structure spread out into energy bands: "allowed" energy bands separated by "forbidden" energy bands. (Rejection bands and pass bands are characteristic of wave propagation in periodic structure, a theory well known to telecommunication engineers for the design of band-pass filters.)
- first appearance also of the *concept of "holes"*, i.e. of the concept of "positive" charges in a crystal, displaced in the reverse direction of an electron under the action of an electric field.

2.6. This brief description of the discoveries which led to the quantum theories must suffice. Several other essential theories which were launched during the same fertile period for science – i.e. during the years from 1925 to 1930 – must, however, be at least mentioned in passing: Heisenberg's indeterminacy principle, Pauli's exclusion principle, the highly sophisticated and formalized mathematical techniques ("The Principles of Quantum Mechanics" by Dirac, published in 1930, Fermi-Dirac statistics, etc.) which were evolved to deal with this new mass of knowledge, etc. ...

From the beginning of the 1930s, the most complex mathematical operations – those of quantum mechanics – were to become possible with regard to the atom. At the level of the atom (and subsequently at that of the nucleus), the mathematical relationships which were revealed thanks to quantum mechanics theory were to prove as significant as those evolved by Newton, almost two centuries earlier, had been for classical mechanics and astronomy.

Both theoretical physicists and mathematicians were enabled to create a coherent system of analysis, a system which would cover and codify all the theoretical concepts which had evolved during the 1910s and 1920s. Despite its admitted complexity, which only a small scientific elite could hope to understand, this system led to many practical results: in addition to the applications of this new science in other fields, it was the interpretation of quantum mechanics which allowed full understanding of the mechanisms of solid-state physics and, in particular, of what initially was so disconcerting in the behaviour of semiconductors.

3. Theoretical and technological researches on semi-conducting materials

3.1. While theory was thus evolving, steady progress was also being made in the study of semi-conducting materials. The behaviour of such materials became the subject of practical and industrial applications even before the phenomena of their behaviour was fully understood. At the end of the 1920s, the rectifying property of junctions between Copper and Copper oxide [10] or of Selenium junctions, was used in the manufacturing of semi-conductor rectifiers to convert alternating electrical current to continuous current. Such rectifiers came into wide use as from the end of the 1930s, especially in power plants for relatively low-capacity telephone exchanges, where they progressively replaced rotating DC-generators.

About 1930, in addition to its use in rectifiers, Selenium – which was among the first semi-conductor materials to attract the attention of physicists at the end of the last century – began to come into widespread use on account of its photoelectric properties, in photoelectric cells to control the opening of doors, in light meters for cameras, etc.

3.2. Although less well known [11] in engineering circles than were the great scientists mentioned in Box C, several physicists – Neville F. Mott in the United Kingdom, Alexander Sergivitch Davydov in the U.S.S.R., and Walter Schottky and C. Wagner in Germany – devoted themselves to explaining the rectifying property of a junction

[10] The rectifying property of junctions between Copper and Copper oxide was discovered by P.H. Geiger and L.O. Grondahl (both United States) in 1926.

[11] Despite the fact that they included a number of Nobel Prizewinners.

between a metal and a semi-conductor. Their investigations were a continuation of the development of the studies on the conductivity of metals which had been undertaken since the early 1930s by the same physicists, as well as others.

In 1931, Professor Alan H. Wilson in the United Kingdom offered a theory of semi-conductors, applying to them the theories of the behaviour and movement of electrons inside the atoms of a metal. His basic book "The Theory of Metals", published in 1936, was followed in 1939 by another: "Metal and Semi-conductors" [7]. Amongst other considerations, A.H. Wilson was suggesting to apply the theory of energy bands derived from the quantum theory and developed for metal conductivity studies to the electrons of the atoms of a semi-conductor crystal. His work on semi-conductors was followed by those of Mott in the United Kingdom, of Schottky in Germany, and of Frenkel, Davydov and Ioffe in the U.S.S.R. [8].

3.3. It was not long before several physicists, making use of the experience acquired in explaining the phenomena of electronic conductivity in a solid, attempted to develop amplifiers which would supersede those using electronic tubes, [9,10].

The "field effect" principle – which is somewhat analogous to the control grid of a triode tube – was the subject of special attention.

As early as 1925, Julius E. Lilienfeld in the United States, who had been Professor of Physics at Leipzig University in Germany, tried to get a solid crystal amplifier to work. In the United Kingdom, another German physicist, Oskar Heil, applied in 1935 for a patent for a semi-conductor device which would be equivalent to a triode tube: a control electrode, corresponding to the grid of the triode, would regulate the intensity of the current flowing through a very thin slice of semi-conducting material. Although Heil's device did not work, it may be considered as a forerunner of the field-effect transistors which were to come into being in the early 1950s.

In 1938 at the University of Gottingen, another German physicist, R.W. Pohl, who had won renown for his work (in collaboration with Wilhelm Röntgen, the inventor of X-rays) on the photoelectric effect and on the luminescent features of a number of solids, envisaged the development of a crystal amplifier. This device, equally analogous to a triode tube, included a metallic network of very fine wires intended to act as a control grid to regulate the electron flow through a Potassium bromide crystal [11].

None of these research projects, however, succeeded in producing a working triode.

3.4. Failing to produce a successful crystal amplifier, studies on the rectifying property of crystalline structures of Germanium and Silicon came to the forefront of research activity in scientific and industrial laboratories at the outbreak of World War II. It became vitally important to design detectors for radio waves at ever-higher frequencies (hundreds of MHz, and subsequently, with the invention of the magnetron, several thousands of MHz) at which radar had to operate (the higher the frequency of radar, the greater its resolution.) Since a long time and from the early days of radiocommunication, crystal detectors ("the galena detector") were used to detect radio wave. Because of their special rectifying properties and of their robustness, detectors based on crystals of Silicon or Germanium were among those most frequently used in radar during the war.

Historians of the war effort of the United States during World War II estimate that more money was spent on the technical development and production of radar than on the atomic bomb. It is therefore hardly surprising that, during the three or four years when industry was put to the service of national defense, the most advanced research on Germanium and Silicon and on their properties was carried out in the United States. The behaviour of semi-conductors was the subject of detailed investigation as well as theoretical studies, and these endeavours led to the discovery of new physical phenomena as well as new theories. Because of their regular crystalline structure (similar to that of a diamond), their chemical composition (as quadrivalent elements) and their electronic conductivity (with extremely

high mobility and long free paths for the electrons), Silicon and, to an even greater extent, Germanium were the semi-conductors on which laboratory work was concentrated. In particular, Germanium became the basis for reference in studies of semi-conductors.

More than forty industrial and university laboratories were engaged in research on semiconductors, under United States defense contracts. In particular, they included the Physics Department of Purdue University where successful work on Germanium was carried out under Professor K. Lark-Horovitz [12,13,14]. "Purdue University's work provided key pieces to the solid-state (amplifier) puzzle" [9, p. 70].

With the end of the war and the winding-up of national defense contracts, work in many of these laboratories on Germanium and on the behaviour of semi-conductors was curtailed or came to a halt. Of the industry-based laboratories, only a few such as IBM and Bell Laboratories survived. Bell Laboratories had, indeed, been concerned with the properties of semi-conductors since well before the outbreak of World War II.

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CHAPTER IV-2

RESEARCH ON SEMI-CONDUCTORS IN THE BELL TELEPHONE LABORATORIES. THE BIRTH OF THE TRANSISTOR [1]

1. From their establishment in 1925 as a separate entity within the Bell System (AT&T), the Bell Telephone Laboratories (hereinafter, and most commonly, referred to as Bell Labs) carried out basic research. Research figured prominently among their activities despite the fact that at first sight it might appear far removed from the Labs' specific concerns, more technical than scientific, and aimed at designing and developing telephone transmission and switching equipment. Before long the scientific successes which were attained in Bell Labs ensured their high reputation among scientists: in 1927 one of the physicists at the Labs, C.J. Davisson, was able to give experimental confirmation of the wave-particle duality of the electron, in recognition of which he was awarded the Nobel Physics Prize in 1937.

During the 1930s, the Director of Research at Bell Labs was Mervin J. Kelly, later to become the Labs' President. A highly perceptive man of science, he was very much aware of the promising prospects of solid-state physics and of research on semiconductors. Even more than the need for the "crystal amplifier" intended to replace the vacuum tube in transmission equipment [1)], Kelly envisaged an electronic device in which a semiconductor crystal would replace the relay as the basic element in automatic telephone exchanges. Thus electronic switching, even before World War II, had been one of the main objectives – if not the objective – of Bell Labs research on semiconductors. In this book on switching, emphasis on these objectives which led to the invention of the transistor simply cannot be exaggerated.

2. During the 1930s and 1940s, there could have been no better scientific environment for exploring the properties of semiconductors and their electronic conductivity characteristics than that provided by Bell Labs. There were many experts gathered in each of the disciplines involved in this many-facetted research. They included some of the foremost scientists of the period (such as C.J. Davisson, already mentioned above), specialists in solid-state physics, some of the most competent experts in such varied branches as crystallography, metallurgy and surface layer phenomena, as well as eminent mathematicians familiar with the latest developments in quantum mechanics. Two outstanding examples must suffice to illustrate the wealth of brainpower which was to be found in the solid-state research department of Bell Labs.

[1)] The theory of "feed-back", applied to amplifiers to reduce their distortion, due to H.S. Black in 1927, enabled the development of carrier transmission systems. These systems, with vacuum tube amplifiers, proved entirely satisfactory: successive generations of these systems, providing 12-channel groups and later 60-channel supergroups, were developed and provided all the capacities needed for the ever-growing "toll" circuits to carry all the long distance traffic which could be foreseen at the time.

2.1. The first example is from the immediate pre-war period, when scientists – mainly in universities – had already achieved considerable progress in theoretical studies on semiconductors.

For studies on crystal detectors to be used in microwave systems [2)], a chemist in Bell Labs, Russel S. Ohl, explored the rectifying property of Silicon crystals. For that research, three metallurgists of Bell Labs – J.H. Scaff, H.C. Theuerer and E.E. Schumacher – developed a process for producing Silicon crystals of high chemical purity by melting in a vacuum [2].

These laboratory-produced samples of Silicon crystals behaved in a curious fashion: sometimes their rectifying effect was in one direction, sometimes in the opposite direction. When the effect corresponded to a negative bias the samples were designated "n" type, when biased positively they were designated "p" type.

Interest was focussed on attempts at understanding what lay at the root of this ambivalent phenomenon presented by semiconductors. A relationship was noted between the behavior of the semiconductor sample and the degree of chemical purity which was achieved in the Silicon used, or, more precisely, the presence of impurities – i.e. of minute traces of substances other than Silicon – in the samples produced. It was observed that crystals of the "n" type resulted from impurities consisting of Phosphorus or Arsenic, while crystals of the "p" type resulted from the presence of Boron. The correlation of this observation with the chemical properties of these substances and to their place in Mendeleyev's Periodic Table (see Box A) was the solution to the problem:

- "p" type crystals were those with impurities ("dopants") of Group III valence;
- "n" type crystals were those with impurities of Group V valence.

This relationship was linked with the theory that the chemical similarity of the elements in a given group within Mendeleyev's Table stems from the similarity of the electron layers of their atoms.

Box A

Most significant elements in Semi-conductor technology *

Group III * (3 valence electrons)	Group IV * (4 valence electrons)	Group V * (5 valence electrons)
Boron (B)		Phosphorus (P)
	Silicon (Si)	
Gallium (Ga)		Arsenic (As)
Indium (In)	Germanium (Ge)	Antimony (Sb)

* In the Mendeleyev periodic Table

Such were at the outbreak of World War II the observations and the ideas which gave rise to the theories which largely influenced, not to say determined, the direction of research into semiconductors in the Bell Labs.

These activities were overtaken by events [3)] and by the outbreak of war. A junction between Silicon types "p" and "n" – the first to have been expressly designed as such – had, however, already been achieved by 1940. (No doubt because of restrictions due to national defence, publications on these topics – and particularly [2] – did not appear until well after World War II, when, following the invention of the transistor, research came to focus on this topic and on the theory of semiconductors.). Research on p-n junctions – this time not of Silicon but of

[2)] These studies were forerunners of the war-time research on radar systems mentioned in Chapter IV-1.

[3)] History does not repeat itself. It has nonetheless been argued that if war had not broken out and if the research team at Bell Labs had not then been dispersed, discovery of the transistor could have been some years earlier, bearing in mind the advanced stage and the significant results which had already been obtained by research in 1940–41.

Germanium – was, however, continued in the United States during the war, and specifically by the team at Purdue University (see Chapter IV-1).

In the listing of the Mendeleyev periodic table, the sequence of the elements corresponds to increasing numbers of protons in their nuclei and correlatively to an increase in the number of electrons around the nucleus.

Elements placed in the same vertical column of the Mendeleyev table have similar chemical properties because they have similar electron structures. The chemical bonding of atoms in a molecular structure, the so-called "covalent bonding", is due to the sharing of their outer electrons with neighbouring atoms to fill their outer electron shells.

Silicon and Germanium are in the same group IV of the table as Carbon: the atom of a group IV element has four valence electrons, i.e. four electrons on their outer electron shell.

2.2. The second example of the diversity of talent among the research team in Bell Labs is provided by a review of the careers [3] of the three men – John Bardeen, Walter Brattain and William Shockley – who won the Nobel Prize in Physics, 1956, for their research and discoveries in 1947 (and 1951) on transistors.

After the war, when Bell Labs resumed research on semiconductors, all three became members of the same team under the leadership of W. Shockley. Each had obtained a Ph.D. in a leading university in the United States and, whether recently or in the more distant past, had been attracted to those areas of research in which they were later to win fame and honor:

(1) Walter Brattain had studied quantum mechanics, based on the theories then still being evolved by E. Schroedinger, at the University of Minnesota during the years 1926 to 1929. In the latter year he had been recruited by Bell Labs starting a career as "surface physicist, first in

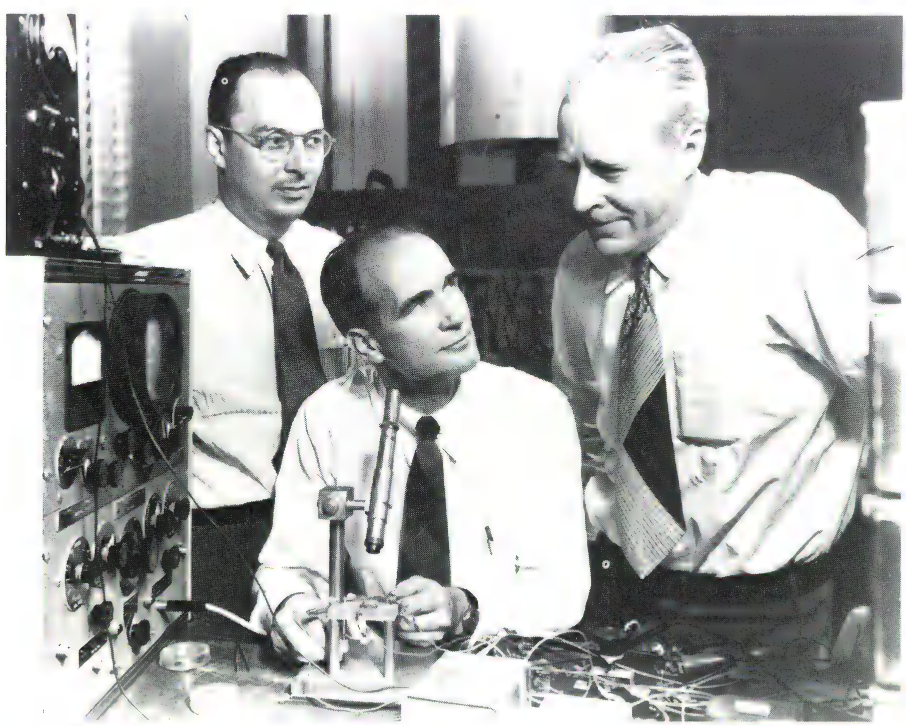

Fig. 1. John Bardeen, William Shockley and Walter H. Brattain (left to right), in 1948, with the apparatus used in their first investigations that led to the invention of the transistor.

thermionics and next in the study of rectification and the Copper-oxide rectifier". He patiently tackled lengthy investigations in attempts to find an explanation for the behaviour of semiconductors. "After fourteen years of work (in that field), I was beginning to lose faith..." when his knowledge of the function of the surface layer of a Germanium crystal, allied to that of his colleague J. Bardeen, made a breakthrough in 1947 with the discovery of the transistor effect and with the invention of the point-contact transistor.

(2) On leaving the Massachussets Institute of Technology (MIT) in 1929, William Shockley had been recruited by Bell Labs' Director of Research, Mervin J. Kelly. His Ph.D. thesis had been on the behaviour of electrons in a crystalline structure. In Bell Labs he was assigned to the Solid-State Research Department.

"Kelly's stimulus for new devices useful in telephone business, plus exposures to new theories about rectification mechanism led me to invent (in 1939–1940) a structure that would have worked as a transistor. With Brattain's help, I experimented with some very crude models that were total failures. But it was now 1940. War-related, non-physics activities kept me busy until I returned to Bell Labs from the Pentagon in 1945". He was then put in charge of a team doing research in his own field of solid-state physics. "I set as one important goal for my group the making of solid-state amplifier structures that would work. I suggested devices using principles like my pre-war idea (what would now be called field-effect transistors or FETs). They failed. But this time the failure was creative. Bardeen explained the failure in terms of the surface states that produced the Schottky barrier at the free surface". And thereupon the point-contact transistor was invented by Bardeen and Brattain, both members of the Shockley's team [4].

Shortly thereafter, when carrying out experiments aimed at ascertaining the role played by surface effects in the development of the point-contact transistor, Shockley was led to make use of a crystalline structure of Germanium "embodying a thin, electrically-positive layer sandwiched between the two electrically-negative ends". He spotted that such a structure also produced a transistor effect. Thus it was that, in 1951, Shockley discovered the junction transistor.

(3) John Bardeen, the youngest of the Nobel Prizewinners of 1956, joined Bell Labs in 1945 as a research physicist after having obtained a Ph.D. from Princeton University in 1936 and after having served for five years at the Naval Ordnance Laboratory in Washington.

As a member of Shockley's research team, by demonstrating the existence of a barrier of potential (the Schottky's barrier) at the free surface of a semiconducting crystal, J. Bardeen became the team's theoretician on the surface states of semiconductors [5].

A set of experiments carried out in close collaboration with W. Brattain, his fellow-worker at Bell Labs (they had shared an office at the Murray Hill, N.J., Laboratory), "with a close interaction between theory and experiment", was to result in their discovery of the transistor effect when, in December 1947, they produced the first point-contact transistor.

3. The discovery of the transistor effect at Bell Labs in December 1947 – i.e. of a process of electronic amplification based on a semiconducting crystal (and no longer by a vacuum tube) – is a major step in the history of technology. "The transistor has changed the world" (J.F. Fisk, in [3]). Its invention marks the beginning of modern electronics in our century. With all the different branches of technology in which the tran-

[4] William Shockley's "Electrons and Holes in Semiconductors" [4], published in November 1950, was – and remains – one of the basic textbooks of science. However difficult it may be to read, the numerous mathematical formulations which it presents retain all their interest today.

[5] One of the theories relating to the surface states of a semiconductor is named after J. Bardeen. Research subsequent to that on the transistor and relating to the theory of supraconductivity was to bring J. Bardeen the rare distinction of a second Nobel Prize in Physics (which, like his first, he shared with two other workers in the field concerned).

Box B

The Birth of the Transistor
(by Arthur Gregor, in [5])

J. Bardeen and W. Brattain were members of a research team which, led by W. Shockley, was engaged in a series of experiments at Bell Labs in 1947. Starting from the fact that a current flow takes place at the point of contact between a semi-conductor and a metal, their aim was to determine whether or not the electric field set up by the current at the point of contact could be made to control the current flowing through the slab of semiconductor. If so, a small signal at the point of contact would cause a large current to flow through the material and this would mean amplification. Shockley called this device the field-effect amplifier because of the weaker current at the contact controlling the strong current flowing through the device. In theory this was sound, but the device itself did not work.

For several months Shockley and his team tried various experiments. He would make adjustments in the design of the amplifier and the team would build and test it. Not once did the amplifier yield what Shockley wanted, but something else – and this was the real step ahead – resulted from these tests. Bardeen had closely watched and studied the behavior pattern of the semiconductors under test and from what he had observed he believed that the key to what they were looking for was in understanding the behavior of the atoms on the semiconductor surface. The others on the team agreed and they now began to test and explore Bardeen's theory. As it turned out they had shifted onto the right track because it was this series of experiments that had led to the invention of the transistor.

The Breakthrough

In teamwork each member can also explore his own ideas, and Brattain had been doing some of his own experiments. He had found out that when light was directed on the surface of a semiconductor, electricity was produced there. This gave further strength to Bardeen's theory that the key was in the way the atoms behaved on the semiconductor surface. Brattain was going on with his tests when one day something quite unexpected happened.

It was during the summer and it was very hot and muggy inside the New Jersey laboratory, which was not yet air-conditioned in 1946. Because of the mugginess, water condensed on the apparatus and Brattain – true to the spirit of the research scientist of not ignoring any observed phenomenon but trying to understand it – decided to continue his experiments inside a liquid. He tried both insulating liquids and water, which is a conductor of electricity. A member of the team suggested that Brattain run electricity through the water into the semiconductor in order to see what effect this would have on the current produced by light on the semiconductor surface. On doing this they observed to their great delight that the strength of the current flowing through the semiconductor increased – in other words, they had found a way of controlling the flow of current through the semiconductor. It was precisely what Shockley had hoped to accomplish with his field-effect amplifier but could not.

At this point everybody connected with the project was getting excited. They were obviously very close to solving the problem of amplifying current in a tiny piece of semiconductor. First they built a model using a drop of water as one of the electrical contacts. But then they replaced the water with a piece of metal, and it was this that led to the team's ultimate success.

Feverishly the team began analyzing the data they were accumulating. Bardeen calculated that the device would amplify effectively if it had two metal contacts no more that about two-thousandths of an inch apart. This distance is so small that the naked eye cannot see it. But they worked with powerful magnifying glasses and it was Bardeen who actually built the first solid-state amplifier. He attached a strip of gold leaf to a bit of insulating material and by cutting through the gold leaf with a razor blade made two contacts. He then pressed these onto a tiny piece of Germanium, which he then put on the top of a piece of metal. A little change of current from this metal plate caused a big change in current flow through the Germanium. The device worked! It was amplifying like a vacuum tube! On December 23, 1947, the team demonstrated this first solid-state amplifier to other Bell Labs scientists. It was a splendid Christmas present for all who had worked on the project for many months.

sistor has come to play such a leading rôle, it ranks with Graham Bell's invention of the telephone in 1876 as an event of outstanding significance.

4. The story of just how J. Bardeen and W. Brattain were led to make the first transistor, the contact-point transistor, has often been told. Their work was – and still remains – a model of scientific research. Of the several accounts which record their achievement, that by Arthur Gregor in [5] may take its place as a significant text in any list of "classics" in the history of technology. It is a real prototype description of the conditions that lead to a scientific discovery. With the kind permission of the author, it is reproduced in Box B.

The reader who will take the trouble to examine this Box and to analyse it as an art critic would describe the merits of a painting (in this case surely a Nativity...) will find all the characteristics which in the science mythology are very often considered as accompanying the birth of an invention:

- the long and patient wait,
- the difficulties and disappointments encountered,
- the suspense and excitement when at last results (the deflection of a needle, proving amplification) are achieved,
- not to mention the light, almost unfortunate, touch due at least to chance, cramped conditions and lack of comfort ("oppressive heat in summer" when air-conditioning had yet to be installed),

all of which combined to touch off the events which ultimately led to success. Similar combinations of features marked various other notable inventions ... To cite only three, consider Pasteur in his poor laboratory of Paris, the Curies in the attic of the Sorbonne or – closer to our field – Alexander Graham Bell when, at the Williams' shop in Court Street, Boston, in March 1876, he had the surprise and joy when, shouting into the mouthpiece of his invention – " Mr. Watson! Come here! ... I want to see you!" –, he succeeded in communicating with his assistant in another room.

5. Arthur Gregor's account stresses the teamwork which was such a predominating feature in this research. The conditions which led to its success have been the subject of many other comments:

5.1. Mention has already been made above of the far-reaching significance of the wide range of skills which were to hand, both within the team itself and, more widely, in the scientific and technological environment provided by Bell Labs.

5.2. In an article [3] published in 1972 to mark the twenty-fifth anniversary of the invention of the transistor, W. Shockley, who from 1946 to 1955 had been leader of the Bell Labs team [6], stressed what he felt to be the essential requirements for orderly research:

- "creative failure methodology" [7];
- "research on the scientific aspects of practical problems".

In the same article he paid tribute to "the managerial art of optimizing the interaction between pure and applied research" which had made Bell Labs "so eminent a leader in innovation".

5.3. No demonstration of that "art of research management" could be more striking than Bell Labs' internal document (the "Authorisation of Works") which, in July 1945 – just a few weeks before the end of the war – established the terms of reference of the Shockley team created to study solid-state physics and semi-conductors. An extract from that document, quoted in [1, p. 71] and reproduced in Box C, shows how precisely and concisely those terms of reference were set forth. The fact that the document was drawn up some weeks before the war had even ended, at a

[6] In 1955, Shockley had left Bell Labs to found his Shockley Semiconductor Laboratory at Palo Alto, California.

[7] "Our failure", he wrote, "to make (in 1947) a 'field effect' transistor was creative. It led to research on the scientific aspect of Bardeen's surface-states".

Box C

"Authorization of Works", July 1945 in Bell Labs – to establish the terms of reference of a group set up to study solid-state physics and semi-conductors.

"Subject: Solid State Physics – the fundamental investigation of conductors, semi-conductors, dielectrics, insulators, piezoelectrics and magnetic materials.

"Statement: Communication apparatus is dependent upon these materials for most of its functional properties. The research carried out under this case has as its purpose the obtaining of new knowledge that can be used in the development of completely new and improved components and apparatus elements of communication systems ... The modern conception of the constitution of solids that has resulted indicates that there are great possibilities of producing new and useful properties by finding physical and chemical methods of controlling the arrangement and behaviour of the atoms and electrons which compose solids.

time when Bell Labs were only beginning to think of resuming their civilian rôle, illustrates the importance and priority which they attached to this particular research.

5.4. Finally, among other aspects, the success of Bell Labs in their research on semi-conductors was due to their concentration of effort along a clearly defined line of enquiry related to Germanium and, later, to Silicon. While research undertaken elsewhere during the immediate post-war period, mainly in universities, was spread over a wide range of semi-conducting materials offering unexpected and interesting scientific properties, Bell Labs in a more pragmatic way were tackling the electronic phenomena of pure crystals of Germanium and Silicon, the most typical and the simplest of semi-conductors. Bell Labs were thus able to take advantage of the very substantial results of war-time research on the physical and electronic behaviour of the two elements.

6. A name for the transistor and its patents

6.1. Once Bardeen and Brattain had discovered the transistor effect, their next step was to apply for a patent – and to give their new device a name.

It was John R. Pierce who suggested the name "transistor": its final "-or" was common to other devices such as the varistor and the thermistor, differing from those relating to electronic tubes, while, by analogy with the transconductivity of a tube amplifier, "transist-" conveyed an idea of a gain resulting from an intensity amplification (*trans*-(res)*ist*ance).

The term "transistor" obtained wide acceptance, and has now been assimilated, unchanged [8], into languages in all parts of the world.

6.2. The drafting of the patent application was no easy matter [1, p. 74]. To give a detailed interpretation of the phenomenon produced in the vicinity of the two points of contact, to explain exactly what happened in the minute area of the crystal of Germanium between the two points, led to most minute investigations and to the establishment of an entire theory of electronic conduction on the surface of the crystal [6,7].

Military clearance had also to be obtained for general publication, in case the invention was deemed to be classified.

Finally, the way was clear, and a public demonstration of the new device took place in New York on 30 June 1948. Neither the general public nor even the scientific press were much impressed [1, p. 74].

[8] For several years, French purists in terminology tried to impose a French equivalent for the term "transistor", which, slightly different from the American term, was "transistron". These efforts were unsuccessful and in French, as in other languages, the term "transistor" prevails.

7. In the Bell Labs, the follow-up

7.1. The reaction in Bell Labs, however, was different. The full significance of the discovery of the transistor effect was immediately recognized, and led to more resources being provided for research on semi-conductors and on the transistor.

This work went ahead on several fronts:

- theoretical studies undertaken in mathematical physics by Shockley, who analysed the electronic behaviour of a semi-conducting crystal;
- a theory developed by Bardeen on the surface state of such a body;
- crystallography and chemical experiments aimed at evolving a semi-conductor as a pure crystal and at determining ways and means of "doping" such a crystal (i.e. controlling the "impurity" content in the crystal);
- applications of transistors to electrical circuits in telecommunications explored;
- etc.

As a result of all this research, major progress was made by Bell Labs during the period 1948 to 1952: many new kinds of transistors, a series of processes for their manufacturing and a wide range of practical applications were evolved.

8. New kinds of transistors

8.1. W. Shockley had been investigating what was exactly happening inside a semi-conducting crystalline body. His calculations enabled him to forecast, as early as 1948–49, the structure of a *junction transistor* [9], namely, a "region" of type "n" sandwiched between two "regions" of type "p". He stressed the potential uses of such a structure, in which the two outer "regions" of the "sandwich" would serve the same functions as the two points of a contact-point transistor [8,9].

In 1950 the combined efforts of some of the Bell Labs' staff, in a team of metallurgists, crystallographists and chemists led by Morgan Sparks [10] were able to produce such a structure. G. Teal [11] and J.S. Little developed a method [12] of growing a Germanium crystal by slowly pulling ingots from the melt, and of "doping" it by layers, by adding minute traces of adulterant material with valencies of III or V types as the crystal grew. Slices cut from the resulting crystal had the structure required for a junction transistor [10]. Thus, the grown junction transistor was the first practical form of the junction transistor which Shockley had envisaged.

The junction transistor with its base, its "emitter" and its "collector" (Fig. 2) was to become, in the years ahead, the most widely used type of transistor.

8.2. It was also Shockley [13] who, in 1951, led the evolution of the field-effect transistor (FET) [14,15].

9) U.S. Patent No. 2,569,347 filed June 26, 1948, issued September 25, 1951.

10) At Bell Labs, in 1948, Morgan Sparks had commenced work in the field of semi-conductors, specializing particularly in research into the properties of the "p-n" junction. Later, as a Director of Research, he worked on solid-state electronics in 1956, prior to his work in 1958 on transistor development.

11) Gordon Teal became some years later the Director of Texas Instruments, Dallas, a company which, due to his efforts, became a leader in the production of silicon junction-transistors and, later, of integrated circuits.

12) This method may be considered as an application of the process known as the Czochralski process, from the name of a scientist at the Radar Establishment, Malvern, United Kingdom.

13) Because J. Lilienfeld had applied in 1930 for a patent for a similar device, Shockley was faced with the problem of who had been the first to evolve the field-effect transistor, when he applied for his patent.

14) The acronym "FET" became – and remains – associated with a whole series of special transistors, and particularly with the metal oxyde semi-conductor field-effect transistor ("MOSFET"). Because transistors of this type came into such widespread use, the suffix "-FET" tended to be dropped during the 1970s.

15) It was not, however, before 1957–1958 that the first realization of field-effect transistors would appear. Stanislas Tetzner in France (Compagnie Française Thomson-Houston) is credited with the production of the first commercial FET junction transistor in 1958 [11]. In the same years the R.C.A. laboratories designed field-effect transistors (John T. Wallmark, Paul Weimer), followed in 1962 by the first silicon FET transistors (Steven Hofstein and Frank Heiman) [12].

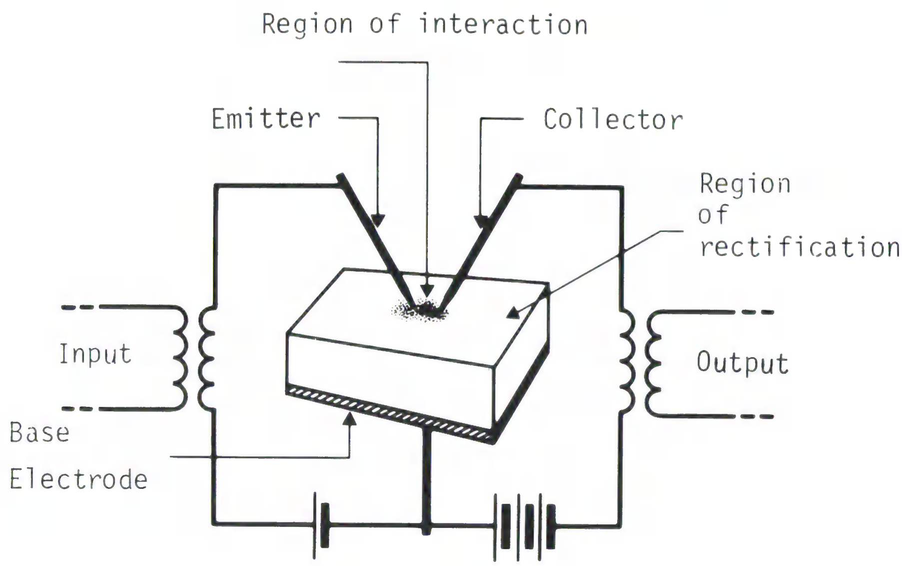

Fig. 2. The junction transistor

This type of transistor differs markedly from both the contact-point transistor and the junction transistor. Those two transistors function by means of *two kinds of "carrier"*:

- negatively charged *electrons*,
- "*holes*" (i.e. a positive-charge corresponding to a void in the atomic structure resulting from the departure of an electron to outside the outer shell of the atom).

Accordingly, the contact-point transistor and the junction transistor are said to be "*bipolar*".

The field-effect transistor, on the contrary, is typical of what is called a "*unipolar*" transistor. In this transistor family, the current passing through the transistor depends solely on the "*majority*" "carriers", which are either electrons or holes.

The field-effect transistor (FET) consists of *a*

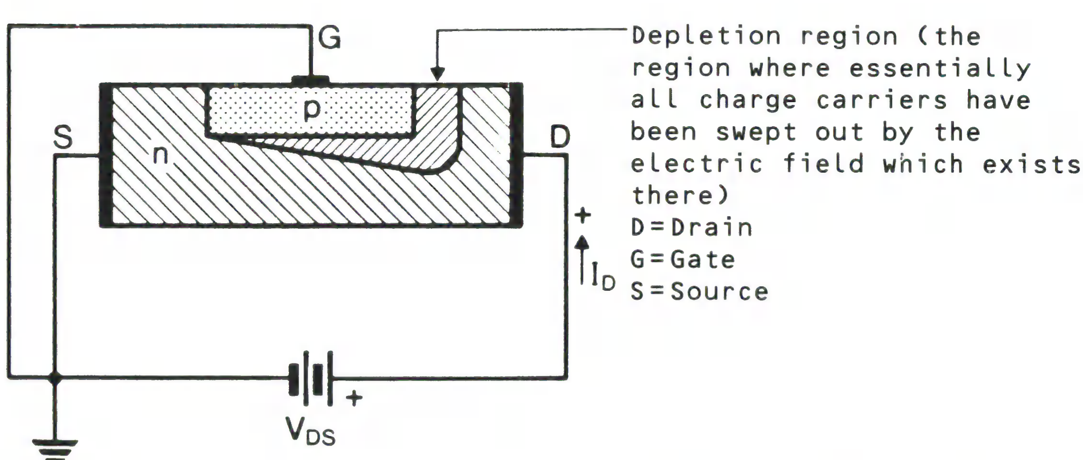

Fig. 3. (Unipolar) Field-Effect transistor, (action depending on majority charge carriers only)

source, a gate and a drain (Fig. 3). Its action depends on the flow of "majority carriers" past the gate from the source to the drain in the semi-conductive channel. The flow is controlled by the transverse electric field under the gate, that varies the conductance of the channel. The original FET designs were of the junction type. They were later superseded by other types, such as the "insulated gate" and, in particular, by the MOSFET type, mentioned in the footnote 14 above.

9. New processes for the production of semi-conductor crystals

While theories and ideas evolved, and while prototype transistors were being developed, Bell Labs were also working out several methods for building the essential crystal structures.

9.1. As already mentioned above, W. Teal and J.B. Little succeeded in 1950 in producing regularly-structured crystals, making use of a single, perfect, laboratory-grown crystal, as distinct from a natural piece of Germanium made up of a collection of small and non-uniform crystals.

9.2. In 1951, two new processses, "zone refining" and "ion implantation" evolved in Bell Labs for the production of semi-conductor crystals.

The first of these processes, "zone refining", due to W.G. Pfann and J.H. Scaff, is a technique for purifying a semi-conductor by "sweeping", or slowly passing, a series of molten zones through a relatively long ingot of impure solid [16]. Germanium purified by this technique was at that time the purest manufactured material (one impurity out of 10^9) [13,14]. The general process of zone melting and the associated techniques that involve crystal growing and adding controlled impurities ("dopants") became the dominant process in the manufacture of Germanium semi-conductor devices.

The "ion implantation" is the technique of modifying the properties of materials by ion bombardment. Early work on this technique began at Bell Labs in the late 1940s and early 1950s by R.S. Ohland and W. Shockley. While the concept of ion implantation was well established in 1951, its potential in design and manufacture was not fully realized in practical designs until the end of the 1950s.

9.3. In 1952, the "crystal pulling technique" was applied to Silicon to produce a crystal possessing the necessary purity and structural uniformity, the "single-crystal silicon". For a number of years, this was to remain the only technique to obtain the silicon crystals for transistors.

Soon after 1952, Silicon came to be preferred to Germanium for transistors because of its better power characteristics and its more suitable behaviour at varying temperatures than Germanium.

9.4. It was also in 1952 that Bell Labs introduced the "basic float zone process", a procedure for purifying materials used in the manufacture of single-crystal semi-conductors. In this process, an elongated ingot is supported in a vertical position while a limited vertical region is melted, yet retained in position by surface tension. The method was particularly useful for Silicon because various effects associated with zone-melting could be achieved without contamination from a container surface.

10. Practical applications of transistors

Finally, Bell Labs were naturally eager to incorporate their transistors in the various pieces of equipment being made for their associated companies within the Bell system (AT&T). Engineers from Western Electric and Bell Labs

[16] As a molten zone advances, the impure solid melts at its leading interface and, due to the difference of solubility between the solid and liquid phases, purified material solidifies at its trailing interface. Each molten zone, which passes through the change carries a fraction of the impurity towards the end of the change. The degree of purification increases with the number of zones passed.

worked closely together in a group set up under the leadership of J.A. Morton. The first task of this group was to collect, from the research scientists, all the technical knowledge needed for the design, development and manufacture of transistors [3]. The group's second – and no less important – task was to build up a body of technical know-how, aimed at the incorporation of transistors in equipment.

As can be seen in the book by Shockley published in November 1950 [4], the transistor – i.e. the contact-point transistor, the only one known at the time – was already described as a quadripole device, the operating condition of which depends on the specification of two voltages and two intensities.

Following these developments, the transistor, like so many other devices which the engineer is called to handle, became for him a "black box" : once he knows its "equivalent circuit", he knows how to incorporate it in the design of a piece of equipment.

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CHAPTER IV-3

THE SPREAD OF TRANSISTOR TECHNOLOGY [1,2]

1. A technological explosion

From the early 1950s onwards, development in transistors and solid state components, their manufacture, and especially their use in every sphere of electronics constituted nothing less than a technological explosion.

2. Spreading the know-how

2.1. The managerial and scientific leaders of the electronics industry were now well aware of the potential of transistor-based technology and its future importance.

The technical spread, implying a transfer of technology, was very largely due to the liberal policies adopted by AT & T as regards the use by other companies of patents which had been taken out by its subsidiaries, Bell Labs and Western Electric. For US$ 25,000 [1], a company – whether American or foreign – could have access to these patents [2].

2.2. Transistor technology became the topic of ever more numerous seminars, lectures and symposia, both inside and outside the United States, with sometimes more than a thousand participants. While during 1948 and 1949 such gatherings had been organized solely by Bell Labs or by AT & T, they soon came to be held under the auspices of various learned societies – and, in the United States in particular, under those of the Institute for Radio Engineers (the forerunner of the present IEEE), the membership of which, even then, ran to several tens of thousands.

2.3. Meanwhile, the first articles on transistors began to appear in the technical press. For a variety of reasons, however, some years were to pass before there was any great number of such articles. For one thing, it took some time for prospective authors to absorb and fully understand the numerous theoretical aspects of the behaviour of a semi-conductor, before they could provide an easily understood explanation of how a transistor behaves. Moreover, one had to have something new to say if one hoped to achieve publication in a high-level scientific review.

Evidence of the arrival of the transistor on the worldwide scene is to be found in an excellent article "Transistor" [3], in the Telecommunications Journal, September 1952, published by the

[1] Their small size and small amount of power needed to operate them made transistors particularly appropriate for use in hearing-aids. In a philantropic spirit, and in memory of Alexander Graham Bell whose earliest research work had been on ways of overcoming deafness, AT&T licensed companies manufacturing such aids to use its transistor patents free of charge.

[2] In 1952, the number of transistor licensees under Western Electric patents totalled 26 "domestic" (United States) and nine foreign ([1], page 75).

Box A

Silicon Valley

Silicon Valley in Santa Clara County, California, south of San Francisco Bay, is universally known as a center of microelectronics innovation and has been cited everywhere as an example of a high technology bastion. It was one of the two places (the other being Dallas, Texas) where the microchip was invented and produced.

Silicon Valley owes its technological renown to a whole complex of industries (more than 3000 companies – generally medium-sized or even small firms – in comparison with the large industrial groups of the telecommunication industry), installed there within a radius of about 20 miles. They form a very closely knit geographical network of production units and research laboratories, where highest performance electronic components and circuits can be designed and produced in the shortest space of time. As a result, Silicon Valley also has the flattering reputation of practically mass-producing millionaires (in US dollars), some of them barely in their thirties.

This happy valley, if such it be, owes its good fortune to a whole set of circumstances:

- the first, purely fortuitous and already mentioned, is the fact that W. Shockley, the original theoretician of the transistor, being a native of Palo Alto, went there in 1955 on his departure from Bell Laboratories, to install his own industrial research center, which very soon became a nursery for other research-oriented firms;
- the proximity of technologically renowned universities, such as Stanford University;
- a very active financial market in California and the enterprising attitude of capitalists willing to enter into "joint ventures", often very profitable;
- the West Coast orientation to Japan, now a leading country in the world in advanced electronics;
- and lastly, a not insignificant attraction to those wishing to exercise their activities in key sectors, the favorable climate of California, with its sunshine, its palm trees, its plum orchards and vineyards, with the ocean and mountains close by ...

ITU [3]. In view of the reserve and diplomatic prudence with which the Telecommunications Journal then approached anything concerning scientific discovery or innovation – to say nothing of the interval before any decision to accept and publish an article could be taken, – the mere fact that the article appeared at that juncture shows how widely the significance of the still infant transistor technology was already appreciated in the international community.

3. An explosion of know-how

3.1. The early 1950s witnessed great mobility on the part of the researchers and fellow-workers who had been the first to acquire expertise and mastery in the conception, production and application of this new technique. They moved from company to company, from industry to university and from university to industry, in a state of almost feverish activity, which culminated in a virtual explosion of know-how. (All this activity and explosion of know-how was, on the human scale, in many ways not unlike the free motion and collisions of electrons inside the atomic structure of a semi-conducting crystal, of which the flux, initially random, is controlled by the electric field in the gate to produce the phenomenon of amplification.)

[3] The Telecommunications Journal hastened to give credit where credit was due, by publishing in its following issue (October, 1952) a short – indeed, very short – bibliography, listing a mere seven articles which had been published in scientific journals, plus 3 books. When looking back, today, on the "big names" of the period, it must be borne in mind that this was 1952 and that four years were to elapse before the award of the Nobel Prize to J. Bardeen, W. Brattain and W. Shockley brought official recognition of their discovery of the transistor effect.

3.2. All that intense activity during the early 1950s in the United States was to prove of far-reaching significance for the establishment of the electronics industry in that country for several decades ahead.

3.2.1. In 1954, W. Shockley left Bell Laboratories and founded his own "Shockley Semi-conductor Laboratory" in Palo Alto, California [4)]. This undertaking was to experience ups and downs before finally running into financial trouble, but proved to be a very rich and prolific nursery of research talents. Many of those who worked there moved on, in due course, to set up their own companies, mostly in the San Francisco Bay Area in what has since become an important concentration of the electronic industry in the place today world-wide known as "Silicon Valley" (see Box A). In this connection, particular mention should be made of the setting up in 1957 of Fairchild Semiconductor Industry in Palo Alto.

3.2.2. The Dallas-based Texas Instruments Inc. ("T.I.") which had specialized in the manufacture of geophysical measuring devices, was licensed under Bell Labs' transistor patents and, in 1953, recruited Gordon Teal, Bell Labs' specialist in crystal growth. The subsequent success of research work carried out in the laboratories of Texas Instruments on Silicon transistors (first "silicon transistor" announced in May 1954) was to result in the company, and Dallas, becoming a major focus of activity in the semi-conductors industry.

3.2.3. Although many other examples could be mentioned, the two foregoing examples must suffice. They illustrate well the long-term impact of essentially random events [4)] on the industrial development in a particular part of a country. Town and country planners could usefully study the "seeding" effect – and all the consequences of subsequent events – when an industrial undertaking is thus implanted in a a given area.

[4)] Shockley chose Palo Alto as the location for his company because he was born there!

4. The dazzling results of research [4,5,6]

Table 1 and Fig. 1 below show the chronological sequence of successive innovations in the different stages of transistor manufacture during the period ending in 1961.

4.1. Fig. 2 gives an indication, better than any description, to the dazzling achievements in all directions of scientific innovation during the ten-year period which commenced in 1952: Solar cells, light-emitting diodes (LED), lasers and, in particular respect to the present book, integrated circuits, both scientific discoveries and innovations which marked the technological environment of the second half of this century. Without them, man would never have conquered space.

4.2. The decade 1952–1962 was marked not only by major scientific and technical discoveries but, even more so by what can only be described as phenomenal progress in the industrialized manufacture of transistors.

With the commencement of the 'sixties', the semi-conductor industry entered a new technological era, that of the integrated circuit. The evolution in this area of electronics was marked by successive stages:

- Medium-scale integration (MSI);
- Large-scale integration (LSI);
- Very large-scale integration (VLSI);

and is reviewed in Chapter IV-4.

Table 1
Major milestones in "transistor" electronics between 1948 and 1962
(Source: [6])

Point-contact transistor	1948
Single-crystal Germanium	1950
Grown junction transistor	1951
Alloy junction transistor	1952
Zone melting and refining	1952
Single-crystal Silicon	1952
Diffused-base transistor	1955
Oxide masking	1957
Planar transistor	1960
MOS transistor	1960
Epitaxial transistor	1960
Integrated circuits	1961

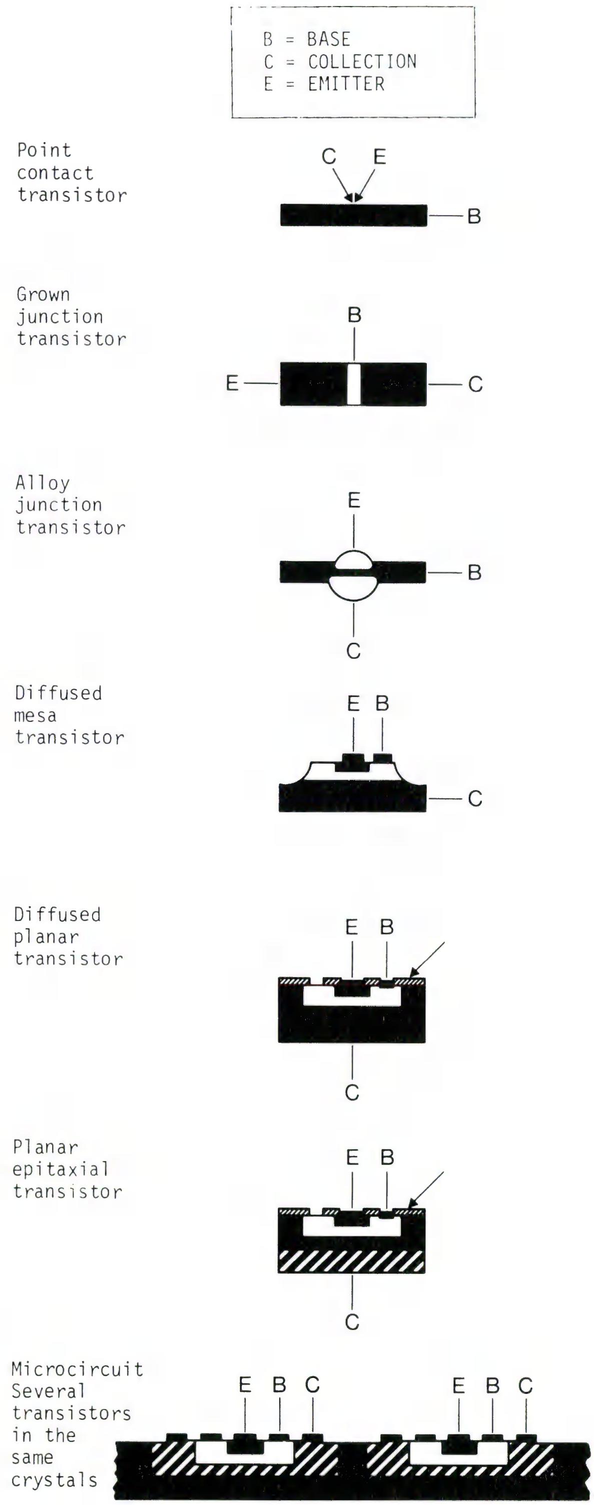

Fig. 1. Different types of transistors [from ref. 7].

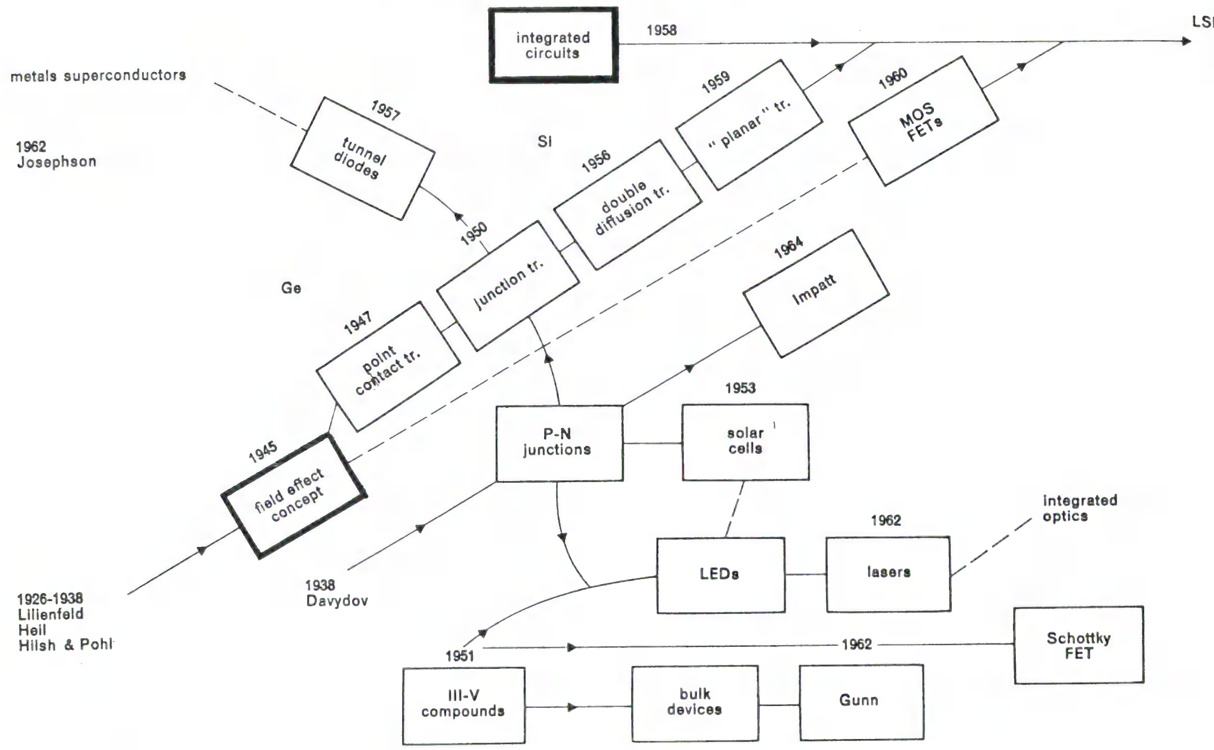

Fig. 2. Schematic illustration of the development path of a variety of semi-conductor devices after 1951 [from ref. 4]

4.3. From the 1950s onwards, Bell Labs were no longer the sole initiator of new developments in transistor technology. Many companies, mostly in the United States but also in other industrialized countries (e.g. Japan and Germany), were active in the immense research endeavor involved. Some of them – IBM, RCA, Sylvania, and General Electric – were amongst the biggest and most strongly-based in the electronics industry. Others, however, were outsiders, newcomers which, thanks to the initiative of their managers and research workers, were able to win a place in the sun, to build up a solid reputation, and to establish a sound footing in a highly lucrative market.

4.4. The semi-conductor industry came into being at a moment when the economic climate was favorable. Wall Street was on the lookout for dynamic companies in the vanguard of technological progress, and in the cold war era of the early 'fifties the United States Department of Defense was keenly interested in military applications of the transistor. The boom was on.

Unlike the human infant, whose rate of growth decreases with age, the infant semi-conductor industry was destined to grow more rapidly with age.

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CHAPTER IV-4

AFTER 1960, THE MICROELECTRONICS

Preliminary Notes

a) This Chapter is intended, essentially if not solely, to give some brief chronological references for those not in electronics, since dozens if not hundreds of books on electronic developments are being published each year for engineers.
b) Whereas the preceding Chapters IV-1 to IV-3 describe achievements in semiconductor technology which have predated the development of the first generation of electronic switching systems (the first SPC systems), Chapter IV-4 concerns inventions and innovations which exerted their impact on switching applications only in the design of post-1970 systems.

1. A short chronology of integrated circuit development [1,2,3,4]

1.1. Jack Kilby made the first integrated circuit at Texas Instruments late in 1958 (patent applied for in February 1959). In this circuit both resistors and capacitors were built into the same silicon chip as the active transistor element, with the metal connections between these components running across the surface of the chip.

1.2. It was in the late 1950s that the convergence of a whole series of innovations and inventions largely developed at Bell Laboratories reached its culmination: use of masks for photolithography, diffusion by gaseous epitaxy of the doping elements through the windows thus created in the silicon layer, and oxide passivation for protection of the junctions on the surface of the chip.

All these technological refinements reached perfection in the PLANAR process developed in 1960 by Jean Hoerni at Fairchild and, concomitantly, by Bell Laboratories, whereby transistors could be created on a flat chip surface.

1.3. In 1959 Robert Noyce of Fairchild had combined these processes with the evaporation of a metal on the protective silicon dioxide surface of a chip to join the components of the integrated circuit and form resistors.

1.4. (For their important inventions for integrated circuits, J. Kilby and R. Noyce were awarded in 1989 the largest American prize for engineering achievement, the Charles Stark Draper Prize of the National (US) Academy of Engineering.)

2. A new industry. Its achievements

2.1. Thus, in the early 1960s the integrated circuit industry was born. It went from success to success. After the 1970s the production of integrated circuits was to become a pillar of the economy in the leading industrial countries.

Using photolithography and micrometallurgy, it has been possible to house all the active (transistors) and passive (resistors, capacitors) components of an integrated circuit on a single chip, together with the connections between them. This enabled the tiny chip to be mass produced and the production processes to be streamlined, although the basic principles have remained unchanged.

All manufacturing processes of this industry take place on a microscopic scale. The lines etched on a chip are measured in microns (thousandths of a millimetre). The lines in the first integrated circuits were several tens of microns thick and each chip could house ten components. By the end of the 1970s, line thickness had been reduced to the order of 3–5 microns and tens of thousands of components were being housed in a single chip, while in 1985 manufacturers were contemplating the 1-micron scale and the incorporation of one million components.

2.2. Initially, the beginnings of the new-born industry were regarded with some scepticism. Of the chips obtained from cutting wafers that had undergone the whole cycle of production processes, the yield after testing for the correct specifications was found to be small, sometimes very small. Indeed, it became even smaller as integration (number of components built into a single chip) increased; but technological refinements in workmanship gradually enabled the yield to increase and, eventually, keep pace with the degree of integration.

The more advanced the refinements in integrated circuit design and the further miniaturization and integration, the costlier the equipment needed for producing chips. However, the equipment was soon amortized by manufacturing production series amounting to millions and, in a highly competitive environment, there was a spectacular fall in the price of integrated circuits, which to a layman may seem unbelievable:

> "Since the invention (in 1960) of integrated circuits, the cost per function performed is falling by a factor of 10 every five years, as is the area of silicon used. The number of gates [1], i.e. the component devices built into the chip, is increasing by a factor of 30 every five years [5, a 1977 reference]."

The technical press and popular scientific publications, including available paperback editions, offer a wealth of information on the drastic fall in integrated circuit costs, as witnessed by the following assertion:

> "A Rolls-Royce would sell at 5 or even 1 dollar had automobile production followed the same downward price pattern as integrated circuits".

A key factor in the microelectronics industry success was thus the mass-production character of its products which allowed to deliver integrated circuits at prices that sometimes were qualified as ridiculously low. The greater the demand for integrated circuits, the longer the production series. Costs fall by a quarter when production is doubled, entailing a long-term snowball effect and leading to dizzy cost reductions.

2.3. A whole series of parameters are used as references to express "levels of performance versus costs" trends. Besides the above-mentioned number of gates, another increasingly used "barometer" is the one describing the complexity of a random access memory ("RAM"): i.e. the number of bits that the memory is able to contain on a single chip. Over the years this capacity increased very rapidly:

- initially 256 bits, followed by a progression always inpowers of 2,
- rising to 1024 ($= 2^{10}$), i.e. 1 K in the trade jargon in 1971,
- and again to 4 K, 16 K, 64 K, 256 K, 512 K.

In January 1984 Hitachi in Japan announced that they have produced a 1 Mbits (1 Megabits) prototype memory, a memory which was commercialized few years after. Since this time the memory capacity on a single chip did not cease to increase at an exponential rate: 2Mbits, 4Mbits, 16 Mbits and, at the time of writing (1989), 64 Mbits memories are considered to be produced in a near future.

Nobody is better qualified than Robert Noyce, one of the creators (if not *the* creator) of the integrated circuit industry, to provide an idea of this spectacular fall in costs and boast increase in performance. He has done so in a series of articles published by "The Scientific American" in 1977

[1] A logic gate is an electronic device that, in its simplest form, produces one of the Boolean logic operators: AND, OR, NOT.

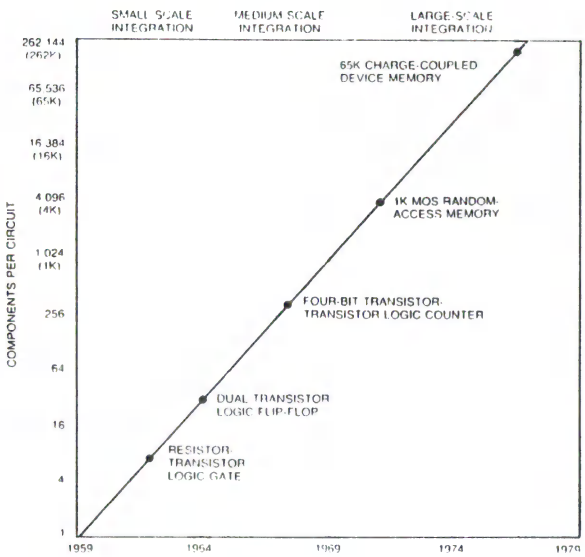


Fig. 1. The evolution of integrated circuits (until 1977) from [5].

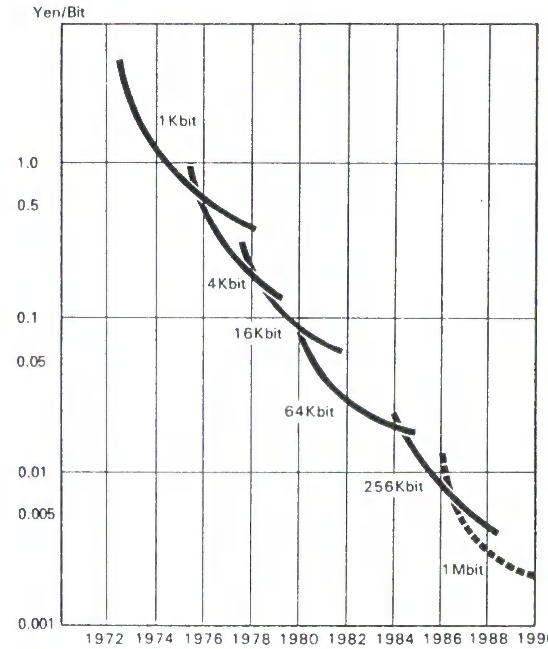


Fig. 3. Cost trends in the development of memory chips from 1972 to 1990 (from [6]).

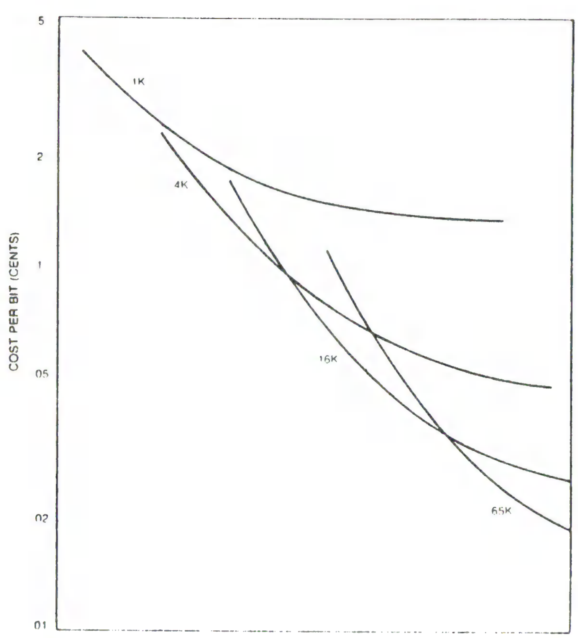


Fig. 2. Cost per bit of computer memory for successive generations of RAM (until 1977) (from [5]).

[5] from which the two graphs in Figs. 1 and 2 have been taken [2].

Graphs illustrating development and forecast increases in integrated circuit capability have become regular features in Symposium lectures and articles of technical literature. More recent than the two figures above, we reproduce three of them, of 1985 vintage, in Figs. 3 (from [6]), 4 (from [7]) and 5 (from [8].

2.4. Miniaturization and integration were to go hand in hand with the speed of operation of the integrated circuit components. Operating time

[2] In 1977, R. Noyce was Chairman of the INTEL Corporation.

The graphs of Fig. 1–2 have been reproduced in various publications, including "Microelectronics and Society", a Report to the "Club of Rome".

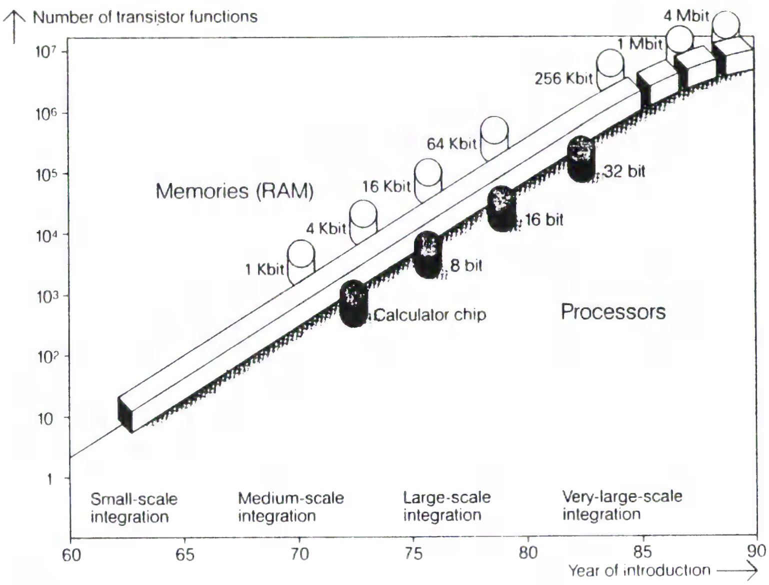
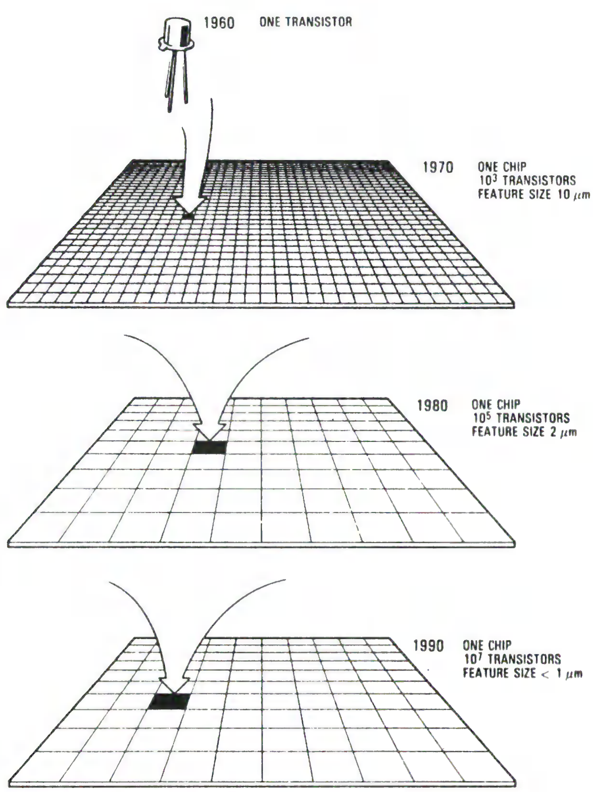


Fig. 4. Increase from 1960 to 1990 in packing density: the degree of integration quadruples every three years (from [7]).



"1985 trends indicate that over the next decade feature size of VLSI circuits will be reduced from 1 micron, which represent the present edge of technology, to perhaps 0.1 micron. This will mean that instead of being able to package one million transistors on a chip, as has already been done in the laboratory, it will become practicable to pack well over 10 million transistors on a chip."

Fig. 5. The reduction of integrated circuit size and the increasing chip complexity (from [8]).

came to be expressed in units smaller than the microsecond, i.e. in nanoseconds (10^{-9} second) [3].

3. In the 1960s, the minicomputer

Minicomputers using integrated circuits appeared at the beginning of the 1960s. It is generally recognized that the first one was designed by Digital Equipment Corporation in 1961: it was a still costly 12-bit 4-K word memory machine. Used in offices and research laboratories, minicomputers found a wide field of applications [4] and were produced by many manufacturers. In ten years their prices were reduced by a ratio of ten to one. New designs of integrated circuits and their use made it possible to improve performance and reduce both the size of the minicomputers and even more their prices. Thus, the hundred or so elements in a 1974 minicalculator had been reduced to only two or three by 1981.

4. Advent of the microprocessor [1,2,9]

4.1. Another major technological step was taken in 1972 when the American INTEL company designed an integrated circuit known as the microprocessor [5]. A complete processor comprising the central unit of a computer, – i.e. an Arithmetic Logic Unit (ALU) – and its control unit was created on a single Large Scale Integration (LSI) chip.

In the following years, "a wave of microprocessor designs, manufactured with a magnitude of differentiated characteristics and architectures, spread in the semiconductor industry like a fashionable women's clothing style". Exciting possibilities were offered to microprocessor users for creating new products and services:

> "Programmed logic could be easily substituted for conventional random logic networks designed with integrated circuits. The information about logical sequences and the output responses of a microprocessor system generated to input signals were stored in memory rather than implementing these sequences with gates and flip-flops".

Hence, the increasing size of the memory and consequently the programming software built into microprocessors. It is noteworthy that in 1972 INTEL became the first company to develop a random access memory of 1024 bits.

4.2. Along with the increase in microprocessor storage capacity, the number of bits characterizing a word, i.e. the basic element of the machine's programming language, became a key factor in determining the microprocessor power (as well as performance levels and, of course, costs). This explains why, as all readers of computer literature know, microprocessors are characterized by their word lengths: words of four, eight, sixteen and even (in 1986) thirty-two bits.

5. Advances in microelectronics after 1970 trigger a third industrial revolution

5.1. Many historians and sociologists have expressed the view that modern electronics using integrated circuits and microprocessors have been ushering in a new industrial revolution that could be described as the Third Industrial Revolution, subsequent to:

- the first, sparked by the steam engine in the early nineteenth century;
- and the second, engendered by the invention of industrial electricity and electric motors, concomitantly with the internal combustion engine for motor cars and aeroplanes, at the beginning of the twentieth century.

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[3] A "merit factor" parameter of an integrated circuit, known as the Function Throughput Rate (FTR), is the product of the number of gates by the maximum operating frequency (now measured in MHz).

[4] "Minicomputers such as the Digital "PDP" series found widespread application in the Bell System operations support system from the beginning of the 1970s".

[5] Microprocessors as defined here, have often been confused with microcomputers. The latter is a complete system including, like the microprocessor, a central unit but also a memory, input/output interfaces and a feed-power element. The term "microprocessor" was introduced only after 1975 and INTEL's first products were initially known as "microcomputers".

Since the early 1980s, the perhaps somewhat mythical notion of the Third Industrial Revolution has become a choice theme of editorials and background articles in the technical press of the telecommunications world, as well as in the opening addresses delivered at countless telecommunications forums and symposia.

5.2. Telecommunications and the prodigious expansion of services that the digitization of their structures offers are certainly an important element of the potential impact of microelectronics and the corollarly Third Industrial Revolution on the way of life of the rising generation. Yet, they represent only one sector of the microelectronics deployment. The mainframe computer industry is a no less important sector: its products equip the decision-making machinery or supports of most industrial organizations and governments. Their operation, in close symbiosis with telecommunication services, are for a human society what the brain and the nervous system are for a human being.

5.3. However the sector which might be considered as the detonator of the explosive deployment of microelectronics turned into the producer of consumer goods for the public.

"Small is beautiful" (P. Schumacher). Freedom of innovation by small companies working independently of the heavy yoke of large industries such as manufacturers of telecommunication equipment or mainframe computers spurted a myriad of new uses for microelectronics. A wide variety of consumer goods was launched on the market. Only a short time – anywhere from a few months to one or two years – was needed for designing and marketing such products, their success reflected in a large-scale distribution. There is no comparison with the time which is needed to develop and bring into service mainframe computer or telecommunication equipment (e.g. a telephone switching system): generally, it takes 5–10 years from the initial research to the final introduction and successful use.

Indeed, since the 1970s, microelectronics byproducts became omnipresent:

- in the everyday life of the individual (e.g. the pocket-calculator), both at home and in his car;
- in business offices;
- in the research departments of industry, as well as in their machinery.

5.3.1. Until the late 1960s microelectronics development had been boosted in the United States by particularly demanding military and space applications [6] and that country reigned supreme over the production of integrated circuits. In 1976 it still covered 71% of the world production [3] while Japan covered another 21% [7]. The Japanese whose production had virtually started in 1968 under a rare joint venture between Texas Instruments and Sony had entered into the microelectronics field for home-consumer products such as desk or pocket calculators, quartz wristwatches [8], television sets and video recorders ..., all markets which have undergone a prodigious expansion.

In addition to their very small size, microelectronic applications for individual use offer the two following advantages which are great assets in consumer use:

- the low voltage needed for supplying integrated circuits (of the order of 4 volts, readily obtainable from small battery cells);
- low power consumption (again implying the use of micro battery cells which the user will not have to change frequently);

[6] For instance, the Apollo project for landing man on the moon, conceived in 1959.

[7] In the same year Western Europe (including American subsidiaries in Europe) accounted for only 6% of the world's production of integrated circuits.

In 1989, the 1976 share of world production quoted above of integrated circuits between the United States and Japan has dramatically changed, with a very large increase of the Japanese share. Western Europe increased only sligthly its share in this world production and newcomers, e.g. South Korea, have become important manufacturers of integrated circuits.

[8] [3] estimates that over a billion pocket calculators and 1100 million digital watches were produced between 1976 and 1982.

5.3.2. Microprocessors sired electronic games. They first appeared alongside juke boxes in bars and game parlours and, subsequently, invaded homes for children's entertainment. It was the birth of a special manufacturing industry with widely publicized brand names.

5.3.3. The appearance of the electronic games somewhat preceded the introduction of the personal computer in the late 1970s. Industrial promoters had discovered a new market-bearing niche and, thus, created a new industry. Its pioneers were American computer engineers fleeing in their escape from the larger corporations or University whizz-kids like S. Jobs and G. Wozniak who had founded and built up APPLE corporation. Following their success, many other new companies and giant companies like IBM, AT & T Technologies and NEC realized which way the wind was blowing and entered into the mass-production market of personal computers: back in 1985 their number in the United States was assessed over 20 million.

5.3.4. Integrated circuit and microprocessor applications have now invaded every aspect of our everyday life. The real factors conditioning the choice of their application for large scale deployment are no longer technical but determined by economical and sociological market studies and eventually by well managed publicity.

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Part V

After the preliminary research, the first development of Electronic Switching, The post 1965 SPC systems

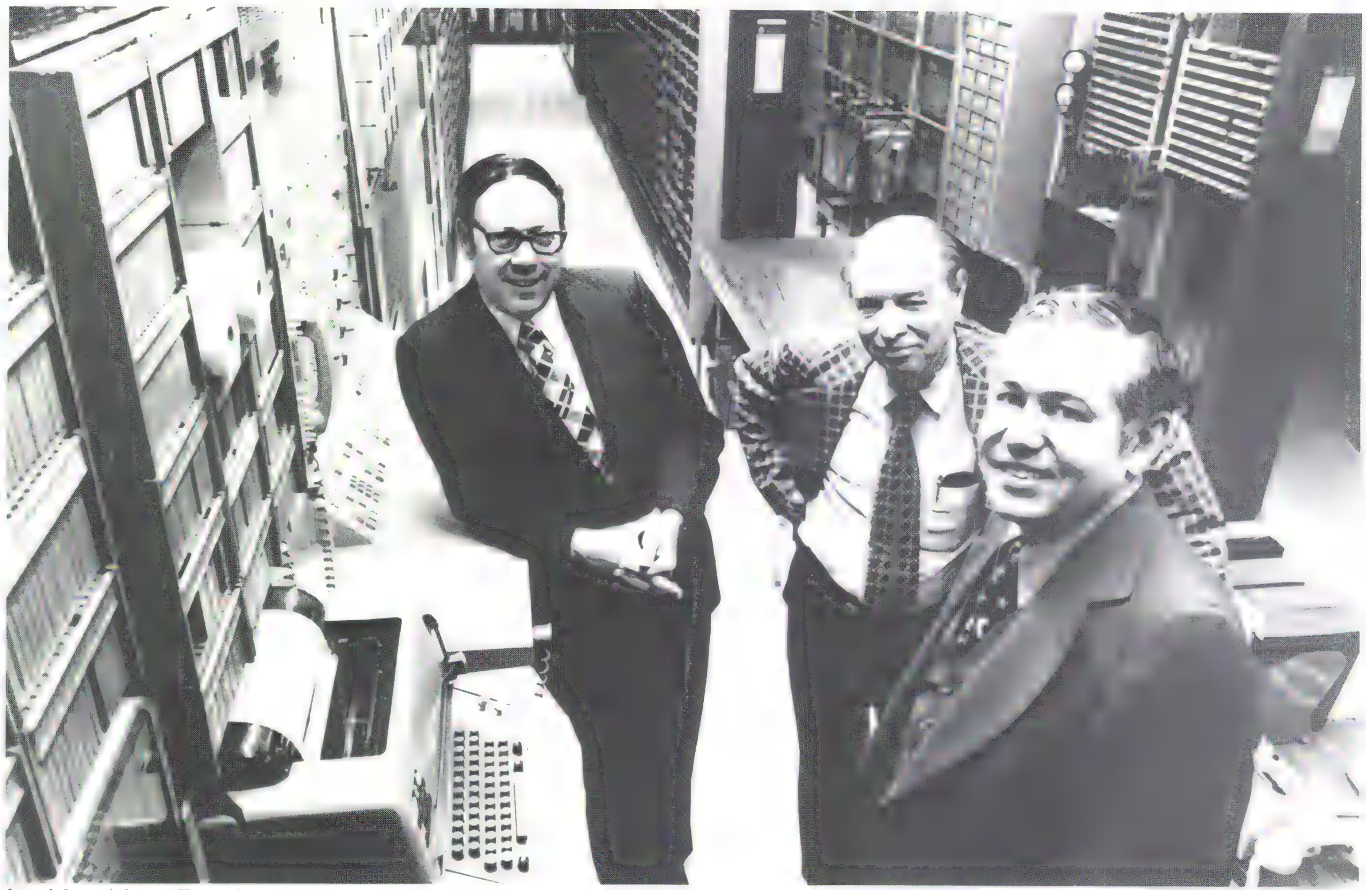

Fig. 1. (*from left to right*) A.E. Joel, W. Keister and R.W. Ketchledge, recepients of the IEEE Alexander Graham Bell Award for their contribution that culminated in the success of the No. 1 ESS.

CHAPTER V-1

AT&T / WESTERN ELECTRIC DEVELOPMENTS (ESS 1, 2, 3, TSPS, AIS)

1. Introduction

In the words of the first "authorization for funds" by AT&T for studies of electronic switching development, "before an economical design of an electronic switching system can be placed into production, much further development work will be required."

The Morris electronic central office work was funded by AT&T only as an exploratory development or, as some call it, a piece of applied research. This new authorization was funded by Western Electric, whose primary interest was in a system it could manufacture and sell to the Bell operating companies. The new authorization, dated March 25, 1957, was accompanied April 1958 with the establishment of a new Switching Engineering division at Bell Laboratories to develop requirements for the ESS Production system, as No. 1 ESS was then named. Later that same year a tri-company committee was formed between AT&T, Bell Laboratories and the Western Electric Co., "to establish a set of requirements which will result in the shortest possible development and manufacturing schedules for the initial ESS units ..."

While it was expected to take at least five more years and $25 million the aim was to "realize early production of an electronic switching system with flexibility to provide attractive new services while at the same time comparing favorably economically with existing (electromechanical) switching systems."

It took actually 7 years and a development cost of about $42 million [1], not including the manufacturing development. Including this item as well as the cost of the Morris experience, it was estimated that the AT&T spent over $100 million before the first cutover of No. 1 ESS. But much happened in these intervening years. The groundwork and principles, if they may be called that, for all electronic switching were laid. While research continued into many other ideas for electronic switching, the basics to be used in all future systems were being advanced by the work on what was later to be called the Bell System's "number 1 electronic switching system", viz. No. 1 ESS. So basic was the change that the system identification was different from all previous switching systems of the Western Electric Co., viz., the system was identified by the general type of technology and not by the switching network technology employed.

Except for an influence on some Japanese designs, the No. 1 ESS technology was not a model others copied directly. It was the overall architecture and stored program control (SPC) concepts that have left their marks and that

[1] The dollar figures quoted here are from the actual system development cases. Some, such as Brooks who is quoted in Chapter II-2 (Box A), give much higher figures. The differences are usually explained by accounting for which items are included. The system development figures usually do not include:
- device development costs;
- the cost of subsystems that are used on more than one project;
- the manufacturing and installation preparation, tooling, and test equipment development costs;
- the costs associated with initial telephone company introduction such as training.

others emulated. Such things as scanning, signal distributing, hierarchical controls, call storage registers and queues in memory, control hardware duplication, and reliability criteria (did the industry hear about 2 hours of out-of-service time in forty years before this?) are but a few of the principles that were established by No. 1 ESS architecture.

Certainly stored program control has been widely recognized as the single most important contribution to electronic switching. Its use has increased as the processor technology for implementing it has become more economical. Many important new concepts were imbedded in the design of the software, since software was completely new in the design of switching systems. While most of these were discovered by experiences in Morris, the principles were formalized for No. 1 ESS. Such concepts as "network maps" [2)], indirect scanning, cycles and subcycles, real time programming considerations, audit and diagnostic programs are but a few of the new terms that came into general use as a result of this development. Hardly a switching development organization could have existed at this time without having close at hand a copy of the two-part September 1964 issue of the Bell System Technical Journal that described the No. 1 ESS hardware and software and the development process in detail.

From this beginning, the Bell Laboratories developed a product line that served well the Bell System until divestiture changed the basis for development decisions. The following sections describe the principal developments and how they related to one another.

2. No. 1 ESS [1]

While the first No. 1 ESS did not cutover until 1965, the groundwork for its development started during the early exploratory development efforts at Bell Laboratories. Technology was advancing at such a rapid pace that it was obvious before the completion of its design, installation and operation, that the Morris electronic office rather than being the basis for the first production systems, as initially conceived, would be only a trial office.

Furthermore studies had shown that the costs of the Morris design, particularly those associated with the changing of telephone sets were prohibitive. The reader may recall from Chapter II-4 that the Morris design required new low current telephone sets associated with the low current switching network envisioned for electronic switching systems of the future. While this vision of the future was correct, it was for its day too costly. One must remember that the objective of the design from the start was to compete with the current switching systems in production. (Today with the introduction of ISDN, this technical difficulty has been overcome – but with costly circuits at both ends of the subscriber line. When time-division switching was introduced, it has also to be accompanied by the high cost Borscht circuits.) (see Chapter VIII-7.)

As indicated in Chapter II-4, the ferreed invention in 1959 immediately changed the course of electronic switching development in Bell Laboratories. Prior to its invention by Feiner, Lowry, Lovell and Ridinger (see Fig. 2), the principal new technology being considered for No. 1 ESS switching network was a semi-conductor space-division network. Many creative ideas went into this proposal. These semi-conductor pnpn crosspoints were to be made into little pill-like structures that would be shaken into matrix holes and then wave soldered.

The ferreeds provided a major bridge between electronics and electromechanical contacts. They responded to short pulses, they operated rapidly (less than one millisecond), they magnetically latched, they required no holding power, and they were controlled in a manner that required no specific release action. (The arrangement, known as "destructive mark", releases operated crosspoints when another crosspoint is being operated in a path that might result in a double connection.)

[2)] A "Network Map" is the use of control memory to indicate the status, idle or busy, of the elements of the switching network.

Fig. 2. The ferreed's inventors

It should also be noted that unlike electromechanical systems that generally provided two conductors for the speech path and one or more additional conductors for control, the No. 1 ESS switching network used ferreed crosspoints with only two wires. Also the ferreed switches were made into 8 × 8 matrices as compared with 10 × 20 or 10 × 10 for crossbar matrices. This size based upon octal numbers was easier to use in the network map.

2.1. Choice of Technologies (Fig. 3)

Besides the ferreed switch, there were many other new technologies replacing those used in Morris. Memories in particular were the subject of much debate within Bell Laboratories. Outside, the computer industry had pretty much gone to magnetic cores, most of which were being wired very economically in Japan. As has been the case from its beginning, the Western Electric Co. was reluctant to use a technology that it did not make. It could not at that time make magnetic core stores as economically as the Japanese. Instead they opted for the ferrite sheet technology for the random access memory (RAM). They found that these could be produced more economically in the United States where labor was more expensive. In these stores, multiple wires did not have to be threaded manually through the cores. This technology was not new having been invented at RCA several years earlier (see Chapter III-3, section 5.5). The size of the sheet was 16 × 16. An equipment bay provided 8,096 24-bit words.

By 1971 methods of automated production and improved core threading made the introduction of magnetic core memories more economical. Twelve 32,000 word (24 bit) stores were mounted on a single equipment bay. This remained standard until integrated circuit memories were adopted.

Another debate at Bell Laboratories was whether a new technology should replace the very successful "flying spot store" used in Morris. Its greatest drawback was the requirement for the making of photographic plates to be placed in the store before using them. This required that automatic developing equipment had to be provided in each central office.

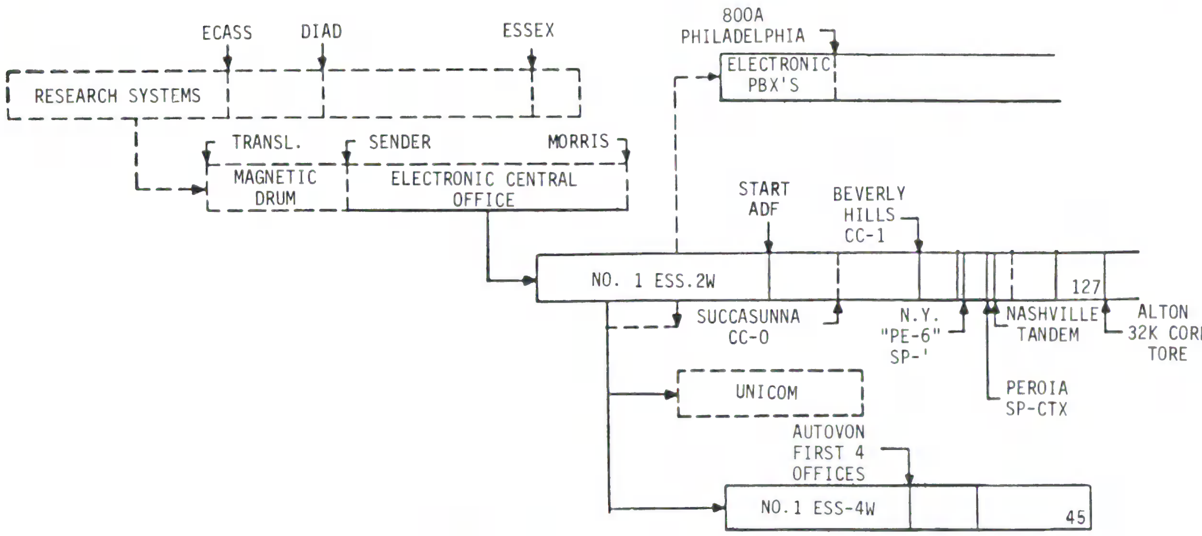

Fig. 3. The development history of the No. 1 ESS

The larger question was whether a separate read-only memory (ROM) was required to contain the program, translation, and other infrequently changed information. For the first generation of Bell Laboratories switch developments, it was decided in favor of two separate storage communities: one, RAM, for the call information and recent translation changes, and the other, ROM, for the program, office parameters, and translation information.

In 1957 Bell Laboratories invented a new type of magnetic storage medium, the "twistor". Here a tape of permalloy is wound helically around a copper wire. A steel plate with small plated magnets is placed under the twistor wire. These magnets are set outside the store by a separate device to store the coded information. This type of store became known as the "permanent magnet twistor" (PMT).

The PMT memory module consisted of 128 removable memory cards each with 2880 magnets for a total of 8096 44-bit words. A complete PMT store of 16 modules provided for 131,000 44-bit words. A special card writer was provided in each office to write the required data onto the card under control of the system, after extraction of the card from the module.

Another technology introduced into No. 1 ESS was the "ferrod". This device was connected to each line and trunk as the high current detecting element. It provided electrical isolation between the sensitive electronics of the office and the vagaries of the outside plant connected to the line and trunk conductors.

During the period between Morris and the start of No. 1 ESS development, great changes were taking place in the design of semi-conductor devices. The greatest change was from the use of germanium-alloy to diffused-base silicon material. It was obvious that the No. 1 ESS would therefore use silicon devices.

2.2. *Design for Production*

From almost the beginning of the Morris project Western Electric engineers worked side by side with Bell Laboratories engineers to ensure that the proposed radical new technology was manufacturable. As a learning experience, Western Electric produced many of the frames used in Morris equipment. This cooperation continued to a greater degree with the No. 1 ESS. From the first cost studies to the final product the cooperation was always very close.

Probably no other aspect of the development was as important a factor in lowering the cost of these initial electronic switching systems as the

design for production. One (AEJ) is reminded of comments received from engineers present at the 1st and 2nd Electronic Switching Symposia of how wonderful it was that the Bell System could afford to place such a very high cost system into development. Most of these engineers were basing their cost estimates upon the component costs alone. This was not the case for the Western Electric estimates. It was the attention that was paid to mass production details and techniques that made reasonable the costs of the introduction of such a radically new system.

2.3. Design of Objectives – Maintenance, Services, Market, etc.

In addition to low production cost [2], the No. 1 ESS promoted, with the Bell System companies that were to use the system, the new maintenance techniques and the new revenue producing potentials of the system. However there were many other objectives of the development, most of which were realized.

The original market conceived for the No. 1 ESS was as a replacement for the aging and almost fully depreciated Panel switching system that was first placed into service in 1921 (see Volume I–Chapter IV-3). Generally these offices were located in the center of large cities. It was not unusual for several central offices to be housed in a single "wire center" building. It was a requirement of the No. 1 ESS to have sufficient capacity to replace several units in the same building. This objective was a critical factor in the success of the No. 1 ESS. There were many large offices in the Bell System that were growing old. They needed to be replaced not only because of the increasing costs of maintenance but also because it was costly to adapt them to new services that were becoming popular. For example Centrex service was available at that time in many of these locations only by using the No. 5 Crossbar System that had been designed originally for lower traffic suburban offices. Therefore the No. 1 ESS design and deployment objective was for a large system with a large market, a situation quite different from other countries.

All of these objectives contributed to the success of the No. 1 ESS in the marketplace. Even though this was an AT&T monopoly market, there had still to be reasonable agreement on objectives for such a large project to be started and to be carried through. But the rational was there and it was not difficult to provide the good arguments that were presented to the US Federal Communications Commission when, as part of their 1971 investigation of the Bell System, they criticized the No. 1 ESS development.

Besides the objectives given above, there were several others that should be mentioned.

Of course, a good price is always set as an objective. In the early exploratory days, one spoke of half cost systems. But this view disappeared quickly with the first cost studies of the Morris office. Eventually after sufficiently high production levels were reached, the price did compete and later was much lower than crossbar systems. Furthermore the advantages of additional revenues from new services and lower maintenance costs clinched the economic advantages of No. 1 ESS.

One incontrovertible advantage of all electronic switching systems, one which has continually improved with the advent of new technologies, is reduced floor space.

Another objective that is discussed in more detail below was the greater capacity to be provided by No. 1 ESS. It was to serve a maximum of 65,000 lines, 16,000 trunks, and to provide for over 100,000 busy hour call attempts (BHCA). Eventually, by 1976, the system provided more than double these capabilities. Even the original figures were well in excess of those then provided by electromechanical switching systems.

From the beginning of electronic switching, particularly at Bell Laboratories, the designers believed that the use of electronics should favor a system architecture that required only one working central control. They were familiar with the many changes that were made to increase the capacity of the No. 5 Crossbar System requiring the division of markers into groups, a division increasing the number of markers. Using the technology of the day, the best that could be

implemented in the 1958–59 period for the ESS was a 5.5 microsecond cycle time for processing control instructions. With the information on program size then available and from simulations, early information indicated that a single working control could carry at the most 50,000 peak busy hour calls.

It was appreciated even then that a large metropolitan office would require much more capacity if it were to serve 65,000 busy lines. For this reason the system architecture was modified to provide a hierarchy of controls. The added level of control, called "signal processors" (SP), was used to preprocess call information, such as deciding when sufficient digits were dialed on a call. This development was started under the name "autonomous call module" in 1961. Originally a plurality of SPs were assumed, but as this development proceeded it was decided that the complexity of this approach could be considerably simplified if only one SP were provided per office. With an SP added to an office, the system was expected to serve 100,000 peak busy hour calls.

2.4. Initial Rate of Deployment

The No. 1 ESS development of features and services to be included in the programs were planned according to the relative need for them. The first No. 1 ESS was cutover in Succasunna, New Jersey, on May 30, 1965. While the objective date for completion of the initial development was the beginning of 1965, this was only a few months late [3]. Considering that it was a completely new system in technology and software, it was a remarkable achievement for its time.

There were at the time 24 Bell operating companies (BOCs). By 1967, two years after the first cutover, each of these companies had installed at least one No. 1 ESS.

2.5. Introducing New Services and Features

Initially the SPC concept was heralded as the alternative to designing complex logic circuits required to carry out the functions of the switching system control. With the expansion of memory capacity required for the programs, its use for new and expanded services and features was proposed in 1954. Morris contained several new services for trial. The No. 1 ESS was required to have the same services and most of the features available in the No. 5 Crossbar system then being deployed by the BOCs. By 1965 the No. 5 crossbar system supported over 500 services and features and this number was continuing to grow. It was said to be a "moving target". While No. 1 ESS was adding new features to catch up with No. 5 Crossbar, development of new features for the latter continued [4].

One decision that arose in developing so many services and features was the treatment of the programs. At that time programming was so new that the designers were not sure they could provide a different mix of services and features in the programs for each office. As a result the concept of "generic" programs emerged and has been used for over twenty years in all of the Bell Labs electronic switching developments.

[3] The original schedules were set in October 1959. The service date was given to New Jersey Bell Telephone Co. as July 1965 with plans to meet a December 1964 date, if possible. Also at that time it was decided that the first installation would be a replacement for a small step-by-step office of less than 4,000 lines.

[4] Not only was the No. 5 Crossbar System the epitome of the modern switching system developer's art, but there was also an element of competition between its developers and those working in the same company on the development of No. 1 ESS. As an example, when "call waiting service" became popular, the No. 5 Crossbar developers tried to add this service to their electromechanical system, but the cost was too high. This provided an existence proof that the new services were much easier and less costly to add to SPC systems. Other examples were given later [3]. At this time many electromechanical switching system development engineeers never conceded the advantages of electronic switching and found it hard to believe that it could then compete with their technology. Then years later, the design and even the production of electromechanical switching systems was to become a "lost" art.

For No. 1 ESS it was decided at an early stage that there would be several families of generic programs. Two were for offices with and without Centrex service. Other were for offices with and without a signal processor. This gave initially a total of four combinations but, since Centrex service was generally popular, programs without this service were dropped in 1972.

As with all switching system developments for the United States market, the process of adding services and features continues to this day. The rate of additions to programs is about constant. There appears to be no lack of new services and features which the market desires. Generally the growth of generic programs is a function of the number of programmers devoted to the task. In this way one can notice the degree to which a company is supporting a system for further development.

Since so much of the further development of a system is involved with the software, which is delivered to the telephone office as a roll of magnetic tape or sent over a data link, it became critical to define a method of payment for system improvements that are not directly associated with deliverable hardware. Another industry innovation that started with AT&T was the "right-to-use" fee. By levying this fee upon users of the programs the software development could be marketed and become profitable. This practice started about 1974.

2.6. Educating the Purchasers (Telecos)

While AT&T, Bell Laboratories and Western Electric were all committed to this project, the Bell operating companies (the "BOCs") were being kept informed of the progress being made in electronic switching. One of the first letters from AT&T to the BOCs was in 1954 announcing the Morris effort. The first letter on No. 1 ESS was circulated in August 1962. From then on there were letters several times a year indicating the objectives of the No. 1 ESS development and providing advanced information for engineering offices. In this way BOCs could start to plan for the installation of these offices as soon as they were allocated from early production.

Perhaps the greatest impact of ESS was on the craftsmen who maintain and operate the central offices. Initially Bell Laboratories engineers visited the BOCs to inform them that a new era was coming concerning the way central offices were to be maintained. They were told that the technology precluded the usual practice of trouble shooting using test instruments such as oscilloscopes. Instead, a new concept known as *automatic trouble locating* would be used. They would need two types of craft, "nurses" and "doctors", the former responding initially to the trouble reports made by the system. For those trouble that they could not correct, a "doctor" from a centralized group would be dispatched. They were also told that, since the major portions of the system were duplicated, this implied that units taken out of service must be restored to service as soon as possible. It they were not, the whole system could stop providing service, an event that is extremely distasteful to the public and detrimental to the telephone company.

While the telephone companies were well informed, as with many radically new systems, they did not believe or perhaps understand all of these implications. They were unprepared for the changes in organization that the new approach would require. There is always great inertia in companies to changes that involve large numbers of personnel. Starting in January 1964 a school was established for lead craftpersons who then returned to their home companies to teach others.

Despite all this preparation, it was only after the companies had obtained first hand field experience that they were able to make the operation of No. 1 ESS and later electronic switching systems a success. Outages occurred, some due to improper maintenance actions and some due to lack of experience in making program changes. As a result the system in the beginning did not meet the anticipated 2 hours in 40 years downtime objective. In the meantime the events received unfavorable publicity that in some cases initially gave No. 1 ESS an undeserved poor reputation.

It was quickly recognized that information learned in school had been quickly forgotten. In general the system had so few items requiring

routine maintenance and the advances in technology were so rapid that the craft personnel were not getting sufficient experience with the system. This then led to the concept of centralized maintenance, a concept which has now gained prominence throughout the world. Nowadays experts are continually challenged with maintenance and operational problems. The first trial of centralized maintenance for No. 1 ESS was started in October 1970.

2.7. Introductory Problems and Rate of Deployment

There were also introductory technical problems in that certain early vintage transistors and reed relays were found in the second installed office to have higher than expected failure rates. All of these were replaced shortly after the defect was discovered. Also later, a batch of poorly performing diodes was found: almost 100,000 circuit packages had to be retested and 14,000 replaced. In general however all components exceeded their predicted failure rate objective.

A most important factor was the call carrying capacity. Throughout the software development, periodic field studies and simulations were made of the expected real time usage. In general they showed that the system should be able to serve as many as 100,000 call attempts. The first few installations were small and utilized only a small portion of the expected capability.

The first call capacity measurements were made with real traffic in the third installed office, in Beverly Hills, California, in 1966. This office was particularly heavy in the use of real time since it contained a number of dial pulse trunks. To the sad surprise of the developers [5)], the true carrying capacity was about half of the objective, viz. about 27,000 BHCAs. A unique methodology measuring the scanning cycles that completed all waiting call processing was devised to determine the true usage of real time capacity.

While this capacity shortfall did not seriously affect Beverly Hills, there were follow-on offices that could have been seriously affected. Extensive reprogramming made it possible within the next year to increase the handling capacity to 32,000 BHCAs and by 1974 this was up to 49,000 BHCAs.

Similar disappointments were anticipated for the SP offices then being installed. Their peak BHCA was estimated at between 59,000 and 73,000. Where great capacity was required in an SP office, another development was undertaken, known as the "service link network" (SLN) [4]. This development was completed in 1970 and increased the BHCA to 83,000. Over the years from 1968 to 1974, through careful and extensive reprogramming, the capacity of the No. 1 ESS with and without the SP was gradually increased until it met the original objectives [5].

The first office with a signal processor ("SP office") was cutover on March 10, 1968 in New York City replacing a famous initial Panel switch known as "Pennsylvania-6".

There was one other problem that received much publicity. The initial system programs were designed so that if the system found itself unable to process calls (a condition known as "phase 4"), it released all established calls. The president of AT&T is said to have exclaimed, "what fools would design a system to release calls under these circumstances?" The trouble phases were quickly redesigned so that under most conditions established calls would not be released and call records would be reconstituted to whatever extent was possible.

In the United States under regulation the telephone companies are permitted to install only sufficient equipment in a central office to take care of the demand for service for a two to three year period. As a result it is necessary for offices to grow while they are in operation. With electromechanical switching this was relatively easy due to the large degree of redundancy in the equipment. With electronic switching most of the critical equipment has at the most duplication. These techniques had to be worked out for No. 1 ESS so that so-called "first growth" offices of each generic program type were important milestones. These techniques were perfected over the period from 1968 to 1970.

A further special growth situation was for

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5) Call capacity is not a single figure but depends upon the mix of call types being processed. Each call of a different type utilizes a different amount of real time to process. To this day most new system developments, particularly those participated in by neophytes, do not meet their advertised BHCA objectives. The more experience one has with the architecture of a particular type of SPC systems, the closer one might come to useful BHCA estimates.

offices that started out with only the central control and had to add at a later date a signal processor. The first such occurrence was in 1971.

The program for Succasunna was only 111,000 words. The first central control (CC) generic was about 150,000 words. By the time Centrex (CTX) service was added the program had increased to more than 183,000 words and the SP added another 31,000 words.. By the time generic SP-CTX 7 had been developed in 1974, the number of words had increased to more than 320,000. This demonstrated that growth in the program occurred consistently with the growth in the new services and features that were implemented by the programs.

The AT&T and Bell Laboratories shared all of the experience elucidated above with those developing switching systems throughout the world through publications, personal interactions and visits, conferences and symposia papers. Except possibly for the No. 4 ESS development (see Chapter VIII-3), no switching development since has been so open and forthcoming. In the press, the problems perhaps were emphasized more than the great accomplishments that brought forth the greatest change in switching since the dial replaced the operator. It was a continuation of an era when throughout the world product quality was the foremost objective in ensuring quality of telecommunications.

By 1974, 9 years after the first cutover, more than 6 million lines of No. 1 ESS were in service in over 500 offices.

A small 200 line version of No. 1 ESS was built in Canada by Northern Electric Co, for use at the Montreal EXPO'67. This was the first of eight No. 1 ESS units to be built and installed in Canada by Northern Electric, predecessor of Northern Telecom.

2.8. Other System Developments (Autovon [6], ADF [7], Unicom [8], 4-wire, etc.)

While the development of No. 1 ESS was proceeding, several derivative developments were started. In September 1963 the United States Defence Communication Agency decided to support the development of a version of No. 1 ESS for their use. This defense application, known as Autovon, was for the military network, a network partially implemented with electromechanical switching.

In this application, the most important difference in technology was the use of four-contact rather than two-contact ferreed crosspoints. The application became known as the "four-wire" No. 1 ESS. This system also had a different program from the versions used for public applications and was designed physically to withstand a greater degree of vibration. Five of these offices were cutover in the first half of 1966 and a total of 12 were placed in service by the beginning of 1967.

It is interesting to note that during the succeeding years these offices had a performance record of far less down-time than two hours in 40 years. This has been attributed to the fact that the program was changed infrequently and no additions were made to these offices. They have been used as a proof of the saying that if you "lock them up and leave them alone" electronic switching offices, if well designed, will perform very well indeed. By 1971, 45 4-wire No. 1 ESS Autovon units were in service, including three in Canada.

Besides the Autovon, another defense exploratory development carried on by AT&T/Bell Laboratories together with ITT and RCA, was a system known as Unicom. This system, developed by Bell Laboratories, used No. 1 ESS technology for the circuit switching of voice, and time-division technology for data and secure voice. Both the space- and time-division switching networks were controlled from the same processor. It also included a data store and forward tape memory systems. It was demonstrated in October 1963 and had a program twice as large as the one for the Succasunna office which did not cutover until almost two years later..

Another development derived from No. 1 ESS was an AT&T supported system initially known as DACS (Data Administrative Communication System) and later as No. 1 ESS-ADF (Arranged for Data Features). The system was developed for a grand entry by AT&T into the data com-

munication network market that was just emerging (see Chapter II-5). Installations in four cities were planned. Several customers had been sold on the concept for their private networks. While the service was later canceled for what might be termed political reasons, the initial development was completed and one office placed into service for an internal AT&T network in February 1969.

3. No. 101 ESS [9]

3.1. Time-Division versus Space-Division

While the exploratory development work was proceeding at Bell Laboratories on subsystems for electronic switching and electronic adjuncts to electromechanical switching systems, such as remote line concentrators, the PBX designers were also considering how they might apply electronics to their systems. At the same time the AT&T top management was learning that their colleagues in Europe, especially in the UK and France, were diligently supporting work on what they considered to be the only true application of electronics to switching, viz. time-division switching. The Research Department had worked on such systems for some years but until that time (1955) had not come up with anything that indicated its superiority over space-division switching.

Even at that time PBX design was very cost sensitive and the studies indicated that applying the Morris type electronics and techniques to PBXs was not practicable. However, examining the remote concentrator project (Chapter II-4, section 3), those studying PBXs hit upon the idea of using remote switching units as PBXs and concentrating the complex and costly electronic controls centrally in the wire center. This plan as it evolved became known as the EPBX. Exploratory development started in 1956 and continued to 1958 when development for production was started about six months after the start of the No. 1 ESS development. (Fig. 4).

Between 1958 and 1960 there was a "stop-go" course of action for this development. When the

[6] It is interesting to note that the philosophy and design objectives used in this processor were similar to the more advanced computers of the mid-1980s of the type known as RISC which stands for "Reduced Instructions Set Computers".

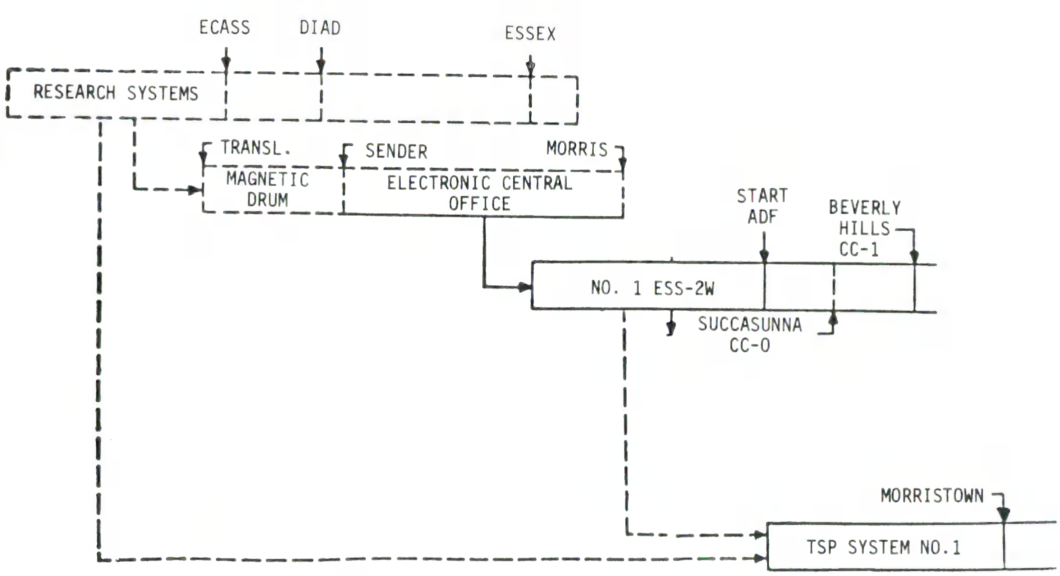

Fig. 4. The development history of the No. 101 ESS

technology for No. 1 ESS had crystalized, the EPBX development, later renamed the No. 101 ESS, was restarted with emphasis on using as much of the general No. 1 ESS technology as possible in the control portion of the system. The principal difference was a smaller, less powerful processor [6]. However it used the same ferrite and twistor memories.

Thirty two remote switch units formed a set of PBXs. The time division switching network of speech paths in each unit used 12.5 KHz sampling rate and 25 time-slots per bus. Later a second bus was added to give greater reliability and an increased capacity of 50 time-slots so that up to 200 heavy traffic lines could be served by a PBX unit.

3.2. Many Firsts of the No. 101 ESS [7]

By early 1963 the No. 101 ESS design was complete and ready for field test. The design included not only the complete central office control but also the interface with the central office "automatic line identification equipment" in associated electromechanical offices. The first trial installation was in New Brunswick, New Jersey. The first production model was placed into service in November 1963 in Cocoa Beach, Florida.

This system represented many firsts. It was the first in-production SPC system successfully employing remote switching units. (Intra PBX calls were completed in the switch units.). It was also the first successful system using time-division switching to be deployed and produced in quantity. Over 200 central control units serving 300,000 lines were ultimately installed. This made it the truly first all electronic in-production switching system.

[7] An anecdote concerning the name of the system: "when it was about to be finalized for production the question of its naming was raised with W.H.C. Higgins who was then responsible for the project. It was agreed that it should be an ESS, but what number? PBXs were generally assigned three-digit numbers. Higgins raised his package of cigarettes and noted that their size was 101 millimeters, and " voila, the system would be known as the No 101 ESS!"

Many of the services and features provided by the No. 101 were also firsts for PBXs: Touch-tone service, identifying outward dialing of calls for station accounting records, providing both PBX and Centrex service for a number of independent customers, first PBX to provide maintenance and traffic records for customers, and many other facilities.

3.3. Marketing of the No. 101 and Increasing its system capacity

The marketing of this system was difficult. The central control expense had to be shared among the several PBXs. This meant that a minimum of 10 or 15 PBX had to be sold within the area of the serving central office.

To accommodate better to the needs of potential markets, a variety of switch units of larger sizes were developed. Their sizes were increased in several interesting ways. First the number of time-slots per bus was increased from 25 to 30 with the maximum capacity of the PBX going up to 340 lines. By 1966 the number of buses were doubled giving a total of 240 analog time-slots serving up to 820 lines. Finally a new technique of combining space and time-division, another first, was employed starting in 1967. This speech path network employed ferreed switches as the first concentration stage of the switching network, giving it a capacity of 4000 lines per PBX switch unit.

Despite all these pioneering achievements and the attempts to develop variations to better meet market conditions, the system failed to obtain large scale acceptance. To become economically viable, the average installation would have had to have a "fill" of about two-thirds its maximum capacity.

4. No. 2 ESS [10]

The No. 1 ESS was economical for large offices. But ever since World War II the Bell System had been faced with serving the growing number of suburban areas. The No. 5 Crossbar system had been developed primarily for this market and was successful in serving it. With the

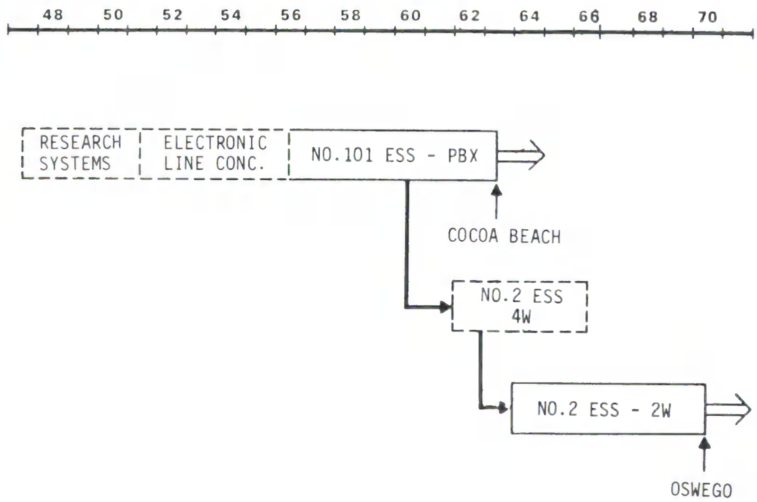

Fig. 5. No. 2 ESS genesis

electronic switching era starting it was necessary to consider a new system to serve this market of small capacity offices. (Another market for a smaller 4-wire system was also at this time the one for the Autovon network mentioned in Section 2 above.). To reduce the cost of the system, it was proposed to replace the two separate stores used in the program and translation processes, i.e. the ferrite sheet call stores and the permanent magnet twistors, by a single memory subsystem.

The technology chosen for this single memory subsystem was a new version of the twistor. This one had a separate wrap of magnetic material that could be set electrically. This eliminated the magnetic cards of the permanent magnet twistors and the special handling process necessary for rewriting the cards. Because of the double wrap nature of the device, it was named the "piggyback" twistor.

The system design started with the development of both two-wire and four-wire versions as an objective (Fig. 5). The four-wire version, intended primarily for the military network, was cancelled in late 1966. Since there was no urgent commitment for a local No. 2 ESS, this cancellation gave the designers a chance to restudy the system that could best serve the smaller office market. (The use of the early designs of the No. 2 ESS for application to a large automatic call distributor for directory assistance calls was considered, but the electronic system could not be made available in time. Instead, No. 5 Crossbar was chosen.)

While the original intention was to use technologies in the No. 2 ESS that were different from the No. 1 ESS, it was eventually decided to drop the piggyback twistor that would have been used for both program and call storage, in favor of the two-store organization and technology of No. 1 ESS.

The logic components of the No. 2 ESS were different from the low level ones of the No. 1 ESS. They were of the "hybrid" transistor-resistor type with both silicon integrated circuits and tantalum nitride resistors placed on the same ceramic substrate.

The program used instructions of two sizes, 21 and 10 bits, two of the latter being placed in one word (22 bits) of memory. Also the call memory allocation was much improved with a single call register.

In general, every effort was made to keep the system simpler and smaller than the No. 1 ESS. Even the magnetic twistor card writer was for single cards rather than whole modules. The program store unit was limited to 65K 22-bit words and each call store to 4K or 8K 16-bit words. The half-word instructions were used for more than 75% of the program. The physical design was arranged so that three

additional units could be added to the system, giving a total program store capability of 256K words. The call carrying capacity was 19K busy hour call attempts with an equal share of intraoffice, incoming and outgoing traffics.

The No. 2 ESS used a one-sided 4-stage ferreed switching network. Its capacity was 2.7K Erlangs serving a maximum of 30K terminations. Nominally the No. 2 ESS was for installations of not more than 10K lines. For larger installations a double office configuration was proposed but never developed. The general economic application range of the system was between 4K and 10K lines and was limited by the capacity of the call processor.

Since this system was for small offices it was appropriate that all elements making up the installation should be examined for improvement. One of these elements was the distributing frame through which all connections are made between the central office equipment and the outside plant. A compact one-sided distributing frame was developed and it was the forerunner of important future developments in this area.

The first No. 2 ESS was cutover in Oswego, Illinois, in Nov. 1970. By 1983, 217 systems of this initial design were still in service. In addition there were 493 offices of the later No. 2B ESS design (see below), many of which were converted from No. 2 ESS. Over 4.2 million lines of these two systems were in service at one time or another.

4.1. Other Versions (2A, 2B, 2C) [11]

The No. 2A ESS was a transportable version of the system intended to be completely constructed and tested in the factory and brought to a site prepared with a building precast foundation. It was first placed in service in Nov. 1972, but this technique was found to be much too expensive and very few were placed in service. A newer development, known as "hot slide-in", later replaced this technique.

The control unit of the No. 2 ESS used the hybrid technology. By the time the system was in production, the technology had advanced to integrated circuits. New ideas on central controls (CC) were proposed to increase the call processing capacity of the system. A new central control known as the "3ACC" was developed. The word size was increased to 24 bits and integrated circuits were used for logic and memory. A microprogram memory enabled the control to emulate programs written for the No. 2 ESS, making it downward compatible. Volatile memories were avoided for the storage of programs. Several steps were taken in the design of the 3ACC to deal with this by making the central control more integrated. For error detection, the logic was made self-checking and the matching between the main and standby controls was eliminated.

The No. 2 ESS with the 3ACC is known as the "No. 2B ESS". The system busy hour call attempt capacity was doubled (to 35K). Other features were added such as Centrex and a unique line range extension arrangement with switched-in repeaters. The office without change could serve more than 20K lines.

The first improved No. 2 ESS was a transportable 2C ESS, cutover in Acworth, Ga., in February 1976 and the first regular No. 2B was cutover in Elgin, Il., in June of the same year.

Many No. 2 ESSs were retrofitted with the 3ACC. Some of the removed No. 2 control complexes were used for the control of the Automatic Intercept Systems (AIS) (see below under 6.2). The 3ACC was also used in private networks and as the SPC processor in the No 5 Crossbar Electronic Translator System (ETS) [8]. As indicated by the coding, the 3A was the forerunner of the 3B Processor used by AT&T in their next generation of computers and time-division digital switching systems.

4.2. No. 3 ESS [12]

By far the largest number of offices which needed to be converted from electromechanical to electronic were those below 4500 lines. As the cost of electronic technology was decreasing it was expected that an electronic switching system could be developed that would be an economic replacement for them. Much exploratory effort went into a trying to find, without success, a new technology solution to the small office market in the early 1970s. As a result a system using the same elements as the No. 2B ESS was devised for this market. It was known as the No. 3 ESS. The first of about 170 offices went into service in Springfield, NB in July 1976.

4.3. The 10A Remote Switching System [13]

One might ask why not a time-division digital switch by AT&T in this time frame (1972–1976)? This story is given in Chapter IX-3.

To overcome the interface problems between high current talking and ringing on telephone lines and transistorized switching equipment, a space-division switching system was developed using pnpn crosspoints. To broaden the possible

[8] See Volume I, p. 398

areas of application and to take advantage of the services and features available in the No. 1/1A and 2/2B ESSs, the system was developed as a remote switching system, the 10A RSS. The interface provided all of the basic BORSCHT functions except for the digital to analog conversion of speech. There were 8-line interface circuits and the first stage of the switching network was on a one printed wired card. The network was a folded three-stage network with a basic integrated circuit element of 4×8 PNPN crosspoints.

The system used two 8-bit proprietary microprocessors, which provided for about 6K BHCAs. These processors, equipped with 48K of RAM and 192K of ROM for the program, were used to provide the program for normal operation with a No. 1 or 2 ESS host and to provide basic telephone services at the remote location should the two data links to the host fail. The host could be as much as 280 miles from the 10A RSS.

A basic single 2.2 meter frame of equipment provided service for 1000 lines. A maximum of two frames (2000 lines) could be operated together by the same controls. The trunks and data links to and from the host could be provided by digital subscriber line carrier.

The first installation of the 10A RSS was in service in Clarksville, NY, operating with a No. 1 ESS host. More than 300 are in service (1987).

5. No. 1A ESS [14]

As with many switching developments, it is the follow-on or succeeding designs that are the most successful. This is due in part to the fact that more effort is devoted to the improvement of a known solution rather than making a new architecture work for the first time. Examples of this are the wire-spring relay version of the No. 5 Crossbar, the French E10B (see Chapter VIII-3), the British TXE4A (see Chapter V-6), etc., and even early electromechanical systems such as the German HDW (see Volume 1, Chapter V-1).

Frequently, as a result of introducing such improvements within a period of about five years, a successful switching system may hardly resemble the original system except from the block diagram standpoint. In recent years the applicable technology has changed so rapidly that this process has been accelerated. So great is the desire to introduce new technology to give systems new capabilities, that many of the developers and manufacturers of newer systems, such as the time-division digital systems (see Part IX), are choosing to enter a longer period of evolution, rather than placing completely new systems in development.

The No. 1A ESS was the successor to the pioneering No. 1 ESS. By the late 1960s many expedients had been taken to solve problems that had arisen, principally with respect to call processing capacity and to keep up with the increasing memory requirements and technologies.

The first installation of the No. 1A ESS was the Franklin office in Chicago, IL, in October 1976. The first retrofit of the 1A Processor in a No. 1 ESS was in San Francisco (Folsom Street) in January 1978. It is estimated that the increased capacity available with the No. 1A Processor decreased the demand for new installations by at least 300 No. 1 ESS offices during the production life of the system.

By 1983 the number of 1A ESSs in service surpassed the number of No. 1 ESSs in service. Together (over 1800 entities) they then served over 53 million lines, far greater than any other electronic switching system.

By the time of the first No. 1A ESS cutover, the size of the program had increased to 500,000 words and the number of features and services provided in the program had increased to more than 500 services and features. By 1986 this last number had increased to more than 1000, reflecting not only the viability of the system but also the effect of political and competitive pressures in the United States on the complexity of the system requirements.

5.1. The No. 1A Processor [15]

While the code "1A" implies a system evolved from the No. 1 ESS, the heart of the system, the "1A Processor", was also developed for use in the No. 4 ESS as well (see Chapter VIII-3, Section 4).

In fact its development was started in 1968, motivated initially by the need for a large capacity Processor for the proposed No. 4 ESS and with the aim of including higher speed memory than the magnetic core memories which had been under development to replace the ferrite sheet memories.

Another motivation for the 1A Processor development was the need to increase the call carrying capacity in the No. 1 ESS and to provide the large capacity required for the No. 4 ESS. The expected improvement was initially modest, from 100K to 140K BHCAs, but with possible extension to 160K if changes were made in the peripheral circuits. By the time the new processor was developed and other system improvements made as described below, the capacity for local switching applications was determined to be 240K BHCAs.

Only a few of the higher speed magnetic core 1A Processors were made. The technology was changing so rapidly that by early 1977 the components of the processor memories were changed from magnetic cores to integrated circuits (4Kbits chips). By 1981 16Kbits chips were used. The basic store unit was 65K words of 26 bits (including 2 parity bits).

While the central control logic was duplicated matching their operations, the stores were reorganized. Rather than complete duplication of the increasingly large stores, the program store community was provided with two roving spares while the call store community was provided with sufficient redundant capacity for transient call storage.

Magnetic disk stores (64M bits) were added to contain non-volatile copies of the program as well as infrequently used maintenance and administrative programs.

The most significant technology change in the No. 1A Processor was the use of integrated circuits of the "diode-modified transistor-transistor logic" (DTTL) type. At that time the degree of integration was still modest, some calling it "SSI", "small scale integration". This technology was also adopted in the 3ACC development for the 2B ESS and the time- division network of the No. 4 ESS.

5.2. Development Tools [16]

The need for utility programs using general purpose main frame computers as tools in the development of software was recognized early. The design of the 1A Processor and other subsystems using the "1A Technology", as it was called, led to the development of much improved and well coordinated design tools and data bases. This attention paid to formalizing the software development process was an important innovation in the design of electronic switching systems.

The formalization of the software development process dates back to the 1960s when for the first time large teams of programmers were required to coordinate their efforts on large software projects. Not only were the programmers' design tools formalized but so were the statements of system requirements. These documents agreed to by the system engineers and the designers were formal statements of the design intent of each system feature and service [9].

5.3. Upward Compatibility

Considering the large investment in programming, the 1A Processor was designed with No. 1 ESS program emulation as a basic requirement. An augmented order structure was used that, as in the case of the 3A CC, permitted half-words to be used in new programs.

5.4. Remreed [17]

The ferreed glass-enclosed contacts used in the switching network of the No. 1 ESS were very successful. There were only minor problems with them in service. They proved that a good technological bridge could be found between high speed electronics and slower speed mechanical contact movements.

The ferreed crosspoint assemblies were rather large since an external magnetic path was provided to maintain the state of the contacts open or closed. Almost for the inception of the crosspoint, Feiner, one of their inventors, pursued the idea of the magnetic path becoming part of the reed contacts themselves. Such contacts made from a magnetic alloy known as Remendur had been made experimentally by R.L. Peek in the early 1950's. The principal difficulties in making these reeds commercially were to stamp them cold to retain their magnetic properties and to gold plate them for use as contacts. By 1971 manufacturing processes overcoming these difficulties were achieved. New switches and network

[9] The CCITT effort to formalize similar documents led in the late 1970s to the promulgation of a diagrammatic "Specification and Description Language", the "SDL".

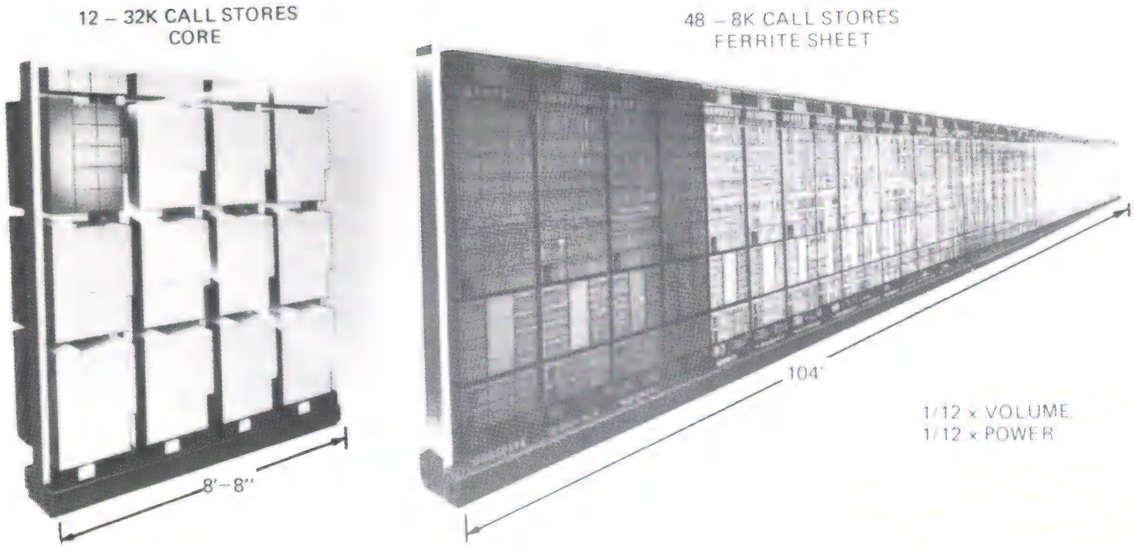

Fig. 6. Reduced floor space obtained with new 1A technology

equipment frames were designed to incorporate the improved crosspoints. The remanent reed contact became known as the "remreed" contact.

The equipment frames using new 1A technology control electronics and remreed switches were four times as efficient in space (see Fig. 6). Two 8×8 2-wire crosspoint arrays could be fitted into a package that formerly held only one array. It is interesting to note that the continuing interest in this crosspoint was heightened when the No. 4 ESS development started in 1968. At that time it was assumed that such a crosspoint could provide the four-wire space-division switching network needed for the toll switching system. Later the fortunate decision was made to use time-division switching in the No. 4 ESS.

The first remreeds were placed in service in June 1973 for the Trunk Link Frames of an office in Detroit, MI. By the next year the remreed had replaced the ferreed for use in all new and growth No. 1/1A ESS offices. Remreed line link frames included a new scanner design that used an improved ferrod line element. About 56 million lines of remreed equipment were made as compared with 8 million lines of ferreed equipment.

5.5. Smaller trunk circuits [18]

With the memory and network subsystems now improved and made smaller, the principal No. 1 ESS elements still needing improvement were the trunk circuits. Using miniature relays, 1A technology, and improved coils and transformers and redesigning the associated scanner and signal distributors, a new Universal Trunk Frame was developed. It reduced floor space for trunk and service circuits by 25%. The first office using these frames was placed into service in Salt Lake City, UT, in 1976.

5.6. Hi-Low 4-wire [18]

In addition to the need for a new large toll switching system, there were many places in the Bell System that could benefit from four-wire toll or tandem switching. In response to this need it was proposed to use four-wire ferreed switches, such as those developed for the Autovon No. 1 ESS (see section 2.8 above). However, these switches were very expensive and No. 1 ESS equipped with them could not compete with electromechanical technology.

A proposal was made to use the regular two-wire ferreed network to offer two unbalanced circuit paths with respect to ground. Fortunately the ferreed (and later the remreed) networks were designed with balance as a stringent requirement. By keeping the receiving-end impedance low, crosstalk could be minimized, and by making the transmitting-end impedance high, two unbalanced paths could be established with a small amount of insertion loss. This scheme, called the "HiLo" arrangement was found to work well. The four-wire No. 1/1A ESS was developed for these tandem switching applications starting in April 1977. About 180 offices with HiLo arrangement were eventually installed, some partially equipped for four-wire switching.

5.7. Switching Control Centers

The concept of centralized maintenance of No. 1 ESS was recognized and implemented early in the deployment of the system (see section 2.6 above). By the mid-1970s electronic adjuncts for operations support systems had also been built into electromechanical switching systems. It is also to be noted that there were many areas with different electronic switching systems, large, medium and small sizes, operator systems, and even No. 101 ESS.

To attain the advantages and important needs for centralized maintenance of this mix of systems, the No. 1 Switching Control Center (SCC) was developed over the two year period from 1972 to 1974. With this system used as a maintenance center for switching systems, computerized displays were used to show the status of all offices in an area and provide quick access to information specific to each office, regardless of its type.

5.8. Interfaces with Operation Support Systems

Just as the No. 1 SCC which required a data link connection to each controlled central office, many other centralized systems were developed to improve the efficiency of the staff required to maintain the quality of the telephone service. These systems included arrangements for billing, collecting traffic data, network management, and other "operations" functions. These systems and their staffs are known collectively as "operations support systems (OSS)".

Each switching system had to include in its hardware and software design interfaces to each of these OSSs. Initially the interfaces were not standardized, but later a version of the CCITT X.25 protocol was used.

5.9. Cellular Mobile [19]

One of the last extensive hardware developments for the No. 1 ESS was the provision for cellular mobile service. Initially this service was to be incorporated into the system as just another service, such as Centrex. In 1975, on an experimental basis, AT&T was allowed to develop the service. The No. 1 ESS was modified to act as a "mobile switching" office for this improved radiotelephone service. This service started in a suburb of Chicago, Il, in late 1978. However, in 1982 the FCC ruled that this service required separate switching offices.

5.10. Equal Access

As a result of the settlement of a legal anti-trust suit against the AT&T in January 1983, the court ruled that by September 1986 most local electronic switching offices in the Bell System had to be modified to provide "equal access" to competing long distance companies. During this period 2600 offices had to have their software modified to include extensive changes in protocols. These changes were made not only in the ESS offices but also in all of the DMS100 offices provided by Northern Telecom (see Chapter IX-5).

This accomplishment is a landmark to the progress made in electronic switching in a brief 20 years since the promises of the SPC revolution were first being proclaimed. The No. 1/1A system includes (1986) more than 1000 services and features. Realizing the importance of what they had created and with the introduction of compe-

tition into this principal United States market, AT & T declared that ESS was more than a set of words. It was an accomplishment to be continually recognized. It then registered these system abbreviations as trade marks.

6. TSP, TSPS [20,21,22]

6.1. Customer Dialing of Calls Requiring Assistance

Even after the advent in the United States of nationwide distance dialing in the late 1950s it was found that the number of special operator handled calls kept increasing. (In the United States customers can place calls to particular parties by name (person-to-person calls), can use credit card and reversed charge calls, and can obtain notification of the time a requested "conversation duration" has elapsed. And, of course, many customers use these services [10]. Studies at Bell Laboratories were directed towards finding ways to reduce operator labor on such calls. C.E. Brooks, the person responsible for the initiation of the ESS studies, proposed that the customers seeking a service that required operator assistance, would dial their called number, when known, preceded by "0". This mode of access to operators would confine operator activities to those requiring their judgement and reduce operator work time.

A new cordless operator position was designed to illustrate how this operator service might be implemented. Trials at New York Telephone Co. demonstrated the feasibility of both the customer dialing of the prefix and the efficiency of the new operator's positions. After the trial, a development was started to add such positions, by then known as the "Traffic Service Position" or, simply, "TSP", to the Crossbar Tandem System. This development was completed and about 21 installations of this subsystem were made.

Systems Engineering studies indicated that to be effective and to serve the entire operator services market, the TSP would have to be added to all of the electromechanical switching systems that provided access to operator services and eventually to the electronic toll switching systems. In addition to Crossbar Tandem the following systems were to be modified: No. 5 Crossbar, No. 4 Crossbar, Step-by-Step Intertoll, No. 1 ESS. Work had already begun on several of these developments. It was then (1963) that R.J. Jaeger and A.E. Joel who were responsible for modifying the Step-by-Step System looked at the technology and found it lacking modernity. Electronic switching was fast becoming the standard. The TSP subsystems were based upon electromechanical technology. Stored Program Control has much appeal for operator services because flexibility is needed to support frequent service changes.

Jaeger and Joel came up with a new system concept. Operator positions are reached from trunks existing between local and intermediate switching offices rather than necessarily being colocated with them. While the concept was simple, selling the idea of a new electronic switching system development when several large local switching projects were already underway was difficult. Furthermore, it was an example of the electronic art forcing out the old electromechanical art with many vested interests. The collection of trunks, a ferreed switching network, an SPC, and the positions formed a system called the "Traffic Service Position System". Being the first, it was called the "No. 1 TSPS".

The system could serve a maximum of 3000 trunks and 320 positions divided into as many as 32 groups. The positions did not need to be colocated with the switching network and control. The voice and data links to the positions could be reached by digital as well as analog (voice frequency) facilities. Physically the position consoles were of an ergonomic design and

[10] These services are related to the American charging mode (based on conversation durations expressed in minutes) of the long-distance calls. Most of these services do not exist outside North America, in countries where the charging of long-distance calls is based on "periodic pulse metering", a system allowing very cheap calls when they are of very short duration, for exemple to know whether a requested person can be obtained. (see Volume I, pp. 338–339 and p. 343).

Fig. 7. The No. 1 TSPS positions

they could be placed in attractively decorated rooms in commercial buildings, closer to where operator labor might be easily available (Fig. 7).

The control for the system was derived from No. 1 ESS with several important changes. The TSPS serves coin toll and other calls where the charges have to be known by the operator as soon as the call is concluded. This required large "charge tables" that had to be changed at short notice at all installations simultaneously. This required an electrically writable non-destructive read memory. Fortunately a memory with the required attributes was by then available, viz. the piggyback twistor memory (PBT) (see above, section 4). In the TSPS system the PBT memory was used for these charge tables, for the program and the call processing storage. It was the first system to use only one storage unit for all memory needs. The control was known as the "SPC No. 1A". SPC was used not only in the TSPS project but also for the addition of SPC to the No. 4A Crossbar system in place of the "card translators" [11] which had similar quick memory change requirements. The No. 4A Crossbar system with the SPC No. 1A was known as the "4A Crossbar ETS" (Electronic Translator System) [23].

The PBTs in the SPC No. 1A were later replaced by the first application of semi-conductor integrated circuit memories.

The first No. 1 TSPS was placed in service in Morristown, NJ, in January 1969. At its peak, over 150 installations were in service.

There were several interesting follow-on developments. One was known as the "Remote Trunk Arrangement (RTA)" where the trunk circuits could be located as far as 200 miles from the

[11] See Vol. 1, pp. 396–397

base unit. The trunk circuits were connected to the base unit through remote concentrators.

Another feature added to TSPS was automatic coin toll calling (ACTS). The initial charge on customer dialed toll calls are announced by special announcing machines. If the caller deposits the correct amount, the call is allowed to proceed. Overtime charges are collected in a similar manner.

The initial operator positions used LED displays. Later the positions were improved and used plasma displays. More than 30K positions were placed into service. The TSPS concept resulted in the saving of more than $1 billion to the AT&T and Bell Operating companies. The TSPS became the vehicle for greater automation of calls that formerly required operators. For example, with the introduction of common channel signaling data bases, automated credit card calls were placed through TSPSs that had been modified to include signal data links to signal transfer points.

The No 1B TSPS was introduced in Redwood City, CA, in March 1982. It uses the new 3B20 processor to obtain an improved capacity of 1.6 times the No 1 TSPS. By 1988 all 152 No 1 TSPSs in the AT&T network were converted to 1B TSPSs.

6.2. Automatic Intercept System (AIS) [24]

In the early 1960s IBM developed an arrangement for processing calls to changed or unassigned telephone numbers, calls that normally had to be routed to operators. When the operator received these calls, she would request the number dialed and enter this number into a computer data base. This data base included new numbers now assigned to customers who had moved. An announcing machine provided the numbers found in the data base. This system was known as a semi-automatic intercept system.

AT&T Bell Labs made a considerable improvement in the use of such a data base. Their design, known as the "Automatic Intercept System" did not depend upon the customer giving the number dialed, but upon the number initially "reached". It used the automatic number identification facilities of local offices, normally used on originating calls, to forward the called number. The AIS system used a version of the No. 101 ESS time-division network and a control version of the No. 2 ESS. About 40 of these systems were placed in service, covering the entire Bell System. The data bases were very large, some containing more than 2 million listings. The first system was placed in service in 1970.

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CHAPTER V-2

THE BREAKTHROUGH OF THE SPC TECHNOLOGY OUTSIDE AT&T A FIRST GENERATION OF SPC EXCHANGES

1. A major technological change throughout the world

1.1. The influence of the AT&T success

The telephone switching industry was greatly influenced by the technical success of the ESS No. 1 in 1965 and, to an even greater extent, by Western Electric's series production of ESS-type exchanges for the Bell System companies. 50 such exchanges were already in use by 1969, i.e. four years after the initial installation at Succasunna. As a result R&D activities at laboratories of every major telecommunication industrialist were in full swing from the mid-1960s onwards.

Crossbar systems had swept from the United States across the Atlantic and Pacific and imposed that technology on Europe and Japan between 1950 and 1965 [see Part VIII of Vol. 1]. Now came a second wave, that of SPC systems, which soon spread in the same way. There is many a slip between cup and lip, however, and some ten years generally elapsed between the initial design studies and the introduction of operational systems. Moreover, the length of this time-lag can be illustrated by Bell Laboratories and AT&T in the United States, if exploratory development began in 1955 on the initial SPC prototype which was to become the Morris central office (1960), is taken as the point of departure, and the deployment of the first ESS No. 1 system from 1965 as the point of success arrival in the United States of the SPC technology.

AT&T made a supreme effort, particularly financial, in developing the ESS No. 1 system. Exchange manufacturers outside the United States, AT&T's stronghold, might easily have thrown in the sponge in the face of such a daunting challenge, particularly since their client administrations (except those in the United Kingdom and the Federal Republic of Germany) had, after a long hesitation, finally took the political plunge in favor of crossbar systems. As a result, they were now in full production of such systems.

However, manufacturers anxious to lead the field were able to steal a march by taking advantage of the experience gained elsewhere, sometimes by means of licensing arrangements (AT&T licensed the technology to all who requested). Their approach, however tentative and hesitant initially, was still on a far more modest scale than that of AT&T and sometimes even involved new lines of research.

Given the initial results of trials of the prototypes produced by the switching industry, final agreement had yet to be reached before the users of systems, i.e. in most cases the national administration of the manufacturing country, started placing large orders.

1.2. Difficult decisions for national Administrations

It was particularly awkward for the administrations to decide on the introduction of electronic systems, particularly SPC systems since the

newest crossbar systems, already in widespread use, were giving full satisfaction to them and to their customers. The decision was thus one of paramount importance affecting the future of their national network. The fairly wide diversity of options concerning the design of the electronic SPC systems offered also placed the decision-makers in a quandry. Make the right choice! Yes, but what was the right choice? The 1970s, particularly at the beginning, were thus a crucial period for the switching industry and a time of industrial challenge to telecommunications policy-makers in the developed countries [1].

1.3. Customers' need for a better service

This period coincided with a genuine explosion in demand for the telephone service.

In many Western countries, the public had completely lost patience with the delays involved in obtaining a connection to the telephone network. Referred to the cost of living, the cost of the telephone service, and especially of the long distance service, had fallen considerably and private individuals who had become accustomed to making greater and greater use of the telephone were becoming increasingly critical of the quality of service offered.

Under pressure from public opinion, i.e. from the electorate, the political authorities in the leading countries of the Western world (except the United States, which had always had an excellent telephone service) eventually realized the potential importance of telecommunications to their national economies. A corpus of socio-economic doctrine, praising the merits of a "technotronic" society, generated by the "Trilateral Commission", a tight-knit group of eminent figures from political and economic circles in the Western countries, was also highly influential in confirming the need for a dynamic official policy to encourage massive investment in telecommunication infrastructures. This led to generous budgets for telecommunications and investment programs phased over several years. With the prospect of large contracts beckoning in their own countries, manufacturers of switching and other equipment began to take an optimistic view of matters and demonstrating a great drive and initiative.

1.4. A difficult task for the manufacturing industry

Manufacturers had to face the task of a radical technological change, from conventional switching to electronic SPC systems. It was by no means an easy task.

1.4.1. They first had to design, often in close cooperation with the engineering departments of the national administration, one (or more) type(s) of switching system(s). Such a system had to be up-to-date and take account of technological developments in electronic components which, in some cases, were occurring so rapidly that they outspaced the prototype studies. Furthermore, the systems had to be adapted to the conditions, specific to each country, of the average local network.

Even more decisive was the fact that such a system had to prove itself economically competitive with the conventional systems already in service. This condition was all the harder to meet in that systems of a design predating SPC were costed on the basis of annual mass production often of the order of several million lines. As an extreme case mention can be made of the German (FRG) network for which more than 10 million EMD-system lines had been already provided in the beginning of the 1960s.

1.4.2. Within the switching manufacturing industry and in the research departments of administrations, most of their leading switching experts had become perfectly aware of the technological developments taking place in the United States.

They had gained their first insight in 1957 at a seminar held by Bell Laboratories at their Whippany and Murray Hill (N.J.) headquarters on the newly tried principle which culminated in the Morris exchange. [This 1957 seminar was later regarded as the first in the chronological series of International Switching Symposia (ISS)]. Literature on the Morris exchange, published in the Bell System Technical Journal (BSTJ) and in

other technical papers, had also found a wide readership everwhere. A second symposium on electronic exchange was held in London in 1960 [2] and the third at Holmdel (N.J.) in 1963. While the second was devoted essentially to describing Britain's Highgate Wood and Bell Laboratories' ESSEX exchanges, the third produced a detailed account of the ESS No. 1 system and its smaller brother, the ESS No. 101 to be used in PABX applications.

However, most switching engineers regarded SPC designing as a radically new approach. They had to abruptly abandon sequential relay operation modes and the logics involved, all of which were matters in which they had become expert through years of experience and practice.

1.4.3. Programming was a virtually unknown discipline in the research departments of most switching manufacturers, except for the few which had had the advantage of being associated under the same trade name with other branches of the same company manufacturing computers: the "big four" of the Japanese communication industry, Siemens and Philips in Europe.

The professional qualifications of many of the research staff thus had to be considerably changed. A new type of specialist, the programmer, had to be recruited. Finding experienced programmers in a branch with a workforce that was still fairly limited often meant talent-hunting in other industries. It also meant training new generations of programmers and turning them into specialists in their new branch, another alternative which emerged at the beginning of research into SPC systems and later.

2. The "first generation" of SPC systems ("space-division switching"). Its principal development locations

2.1. The tremendous conceptual and industrial upheaval that took place in the leading switching equipment firms between 1963 and 1973 revealed nine main poles of development, besides, of course, AT&T and its Bell Laboratories that were first in the field, and counting only those companies which undertook mass production. These nine places of development are the ones described hereafter in the following Chapters of Part V.

2.2. Almost all the systems produced at the time were of the space-division switching type and constituted what we shall call the "first generation" of SPC systems. None of them could be better described technically than by their individual designers and developers. In 1976 an anthology of reprints of key articles was edited for IEEE by Amos E. Joel [3] in a book intended "to provide an historic record and background experience for those designing for the next generation".

This work is an invaluable source of technical documentation: each system is analyzed exhaustively yet in a sufficiently condensed form, while its architecture and structures are carefully analyzed. Every article on a given system ends with a generous bibliography of other articles on the subject.

For anyone interested in chronology and dating the first generation of SPC systems, it is significant that all the articles included in [3] appeared between 1965 and 1975. It should be remembered that an interval of three to five years must be allowed between the exploratory development stage and production, which is generally the only phase that gives rise to publications.

2.3. Any attempt to recapitulate the content of the articles published in [3] and redescribe in detail each system, would be inappropriate in this book. We shall merely summarize information in [3] which gives an historical account of the different stages in the design and realization of such systems and which can provide us with a short description of the main characteristics of their architecture.

The economic, structural and sometimes political considerations which determine the potential markets for manufacturers' switching equipment are obviously decisive for commercial success. By associating those considerations with a chronol-

ogy of technological developments in the period 1963–1973, we shall now take a general look at what might be termed the "geopolitics of the world of switching" at that time.

Using as milestones for our survey the different places where SPC systems were developed, we shall divide them into two categories depending on whether or not the industrial groups in question had a guaranteed market (usually the home market) for their products.

The first and larger category (guaranteed market) may be subdivided according to the influence exerted by the design principles of AT&T's ESS No. 1. This influence was:

- sometimes direct, almost amounting to a transposition, for geographical or historical reasons;
- in other cases more tenuous, more diffuse, and even very specific

Both Canada and Japan fall into the first of these two subdivisions, while three major countries of Western Europe – the United Kingdom, the Federal Republic of Germany and France – fall into the second, together with the United States corporation, GTE.

In the second category (industrial groups not directly associated with telephone service operators), we find ITT, LM Ericsson and Philips.

(The sequential order of the Chapters hereafter is determined by the above categorization and its subdivisions.)

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CHAPTER V-3

GTE (GENERAL TELEPHONE AND ELECTRONICS CORPORATION)

1. GTE, Operator of a large telephone network in the United States and switching equipment manufacturer [1]

Until the divestiture of AT&T and the break-up, on January 1, 1984, of the Operating Companies of the Bell System (BOCs) into seven regional companies [1], telephone services to some four-fifths of subscribers in the United States were provided by these BOCs and the remaining fifth by the so-called "Independent" companies [2]. In 1983 there were some 1,500 Independents scattered throughout the United States (see Fig. 1) and covering roughly half the territory. They were as varied in character as the American landscape itself. For instance, they differed greatly in size, some of them forming part of the country's 500 financially strongest companies [3] and others consisting of small family concerns serving little more than 100 subscribers in rural communities.

[1] Nynex, Bell Atlantic, Bell South, Ameritech, Southwestern Bell, Pacific Telesis Group, U.S. West.

[2] Federated since 1897 within the "United States Independent Telephone Association" (the USITA) (see Volume I, p. 110). When it was joined in 1984 by the nine Regional companies issued from the divestiture of the Bell System, the word "Independent" was dropped from its title and the corresponding "I" from its acronym.

[3] The six largest operating groups in the Independent industry at the end of 1979 were (arranged by size): GTE; United Tel; Continental Tel; Centel; Mid-Continent Tel and the Rochester (N.Y.) Telephone Corp.

By far the largest block of independents consists of companies of the GTE group which, in 1984, were serving almost 18 million subscribers in some 7,500 communities spread over 31 states.

Outside the United States, GTE also has a majority holding in telephone companies in Canada (particularly the British Columbia Telephone Co. on the West coast) and in the Dominican Republic, altogether representing slightly over 2.5 million telephones in both countries. In other words, the telephone network of the GTE companies is as large if not larger than those in the largest European countries.

Like AT&T in the United States prior to 1984, the GTE Corporation is not only a telephone service operating company but also, as its name suggests, an industrial enterprise engaged in the manufacture of electronics and telecommunication equipment. In the latter field, GTE not only had (in the period here considered) industrial firms in the United States and Canada but also overseas companies including the Italian GTE Telecommunicazioni S.p.A. in Milan and the Belgian GTE-ATEA in Herentals. As a manufacturer of switching equipment, GTE can boast of being a direct descendant of the Automatic Electric Company [4] of Chicago, which was set up by A. Strowger to produce the first ever automatic exchanges and provided the initial nucleus around which the GTE empire grew.

[4] The name "Automatic Electric" was in fact the one adopted in 1901 after other styles had been used (Volume I, p. 203).

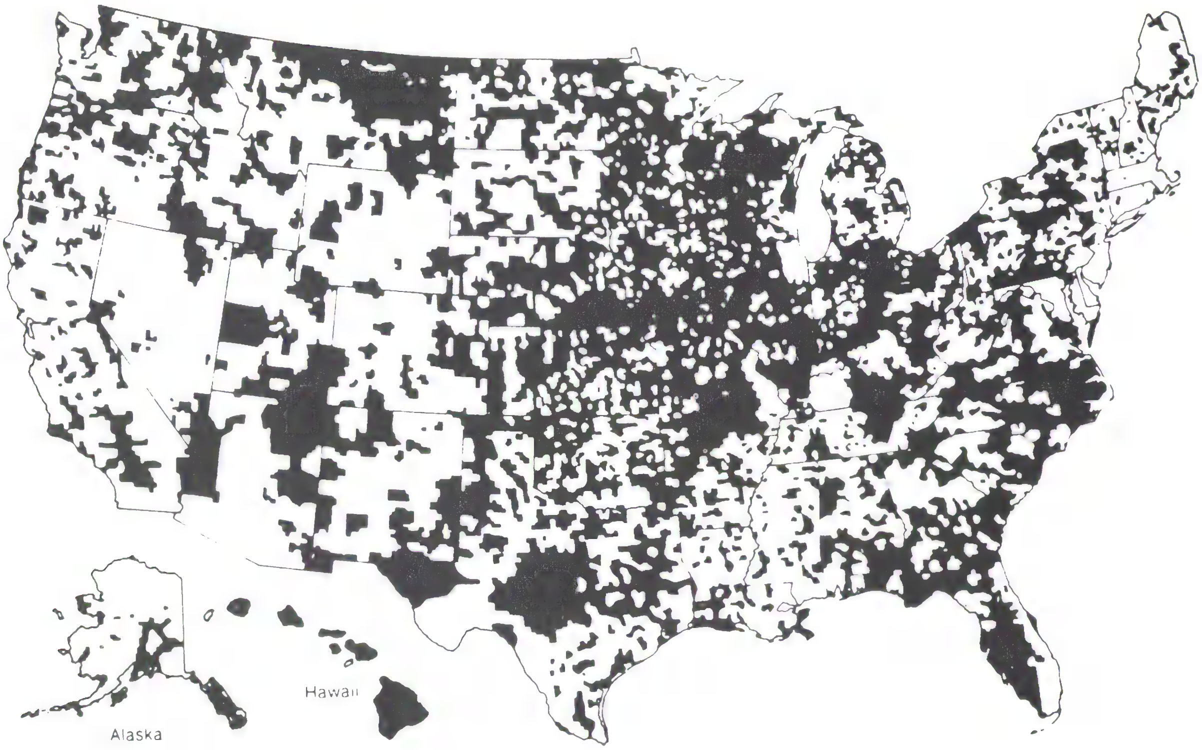

Fig. 1. Independent telephone companies serving 51% of the land area of the United States (black denotes Independent telephone company service areas)

Although Automatic Electric of Chicago was merged with GTE in 1955, its name – famous throughout the world – was still widely used long after.

2. GTE's first steps in electronic switching [2]

2.1. Automatic Electric, too, had in the very early 1960s produced an electronic switching system with a clear objective: "Operating companies need a switching system that will provide new services and thus add to revenues, but not make their existing equipment obsolete".

Its laboratories had started a few years earlier to construct prototype electronic PABXs. The prototypes certainly demonstrated the value of using electronics for switching purposes but they were of a type that required a different model of telephone from those used in the general telephone network, as well as different signaling modes. The aim of research in the 1960s was to develop switching equipment that was in all respects compatible with the equipment already in the network and was even capable of upgrading an existing exchange.

2.2. Most of the GTE Group's switching research in the 1960s was in the hands of Automatic Electric (which was no longer called "of Chicago" as it had been for over 60 years, but "of Northlake": its head office, factories and research shops were moved in 1976 to that little Illinois town some distance from the center of Chicago). For some time before, GTE advanced research in switching was conducted in parallel at Waltham (Mass.) and at its Northlake laboratories (transferred in 1983 to Phoenix, Arizona).

Changing abruptly from direct control step-by-step switching to centralized control switching

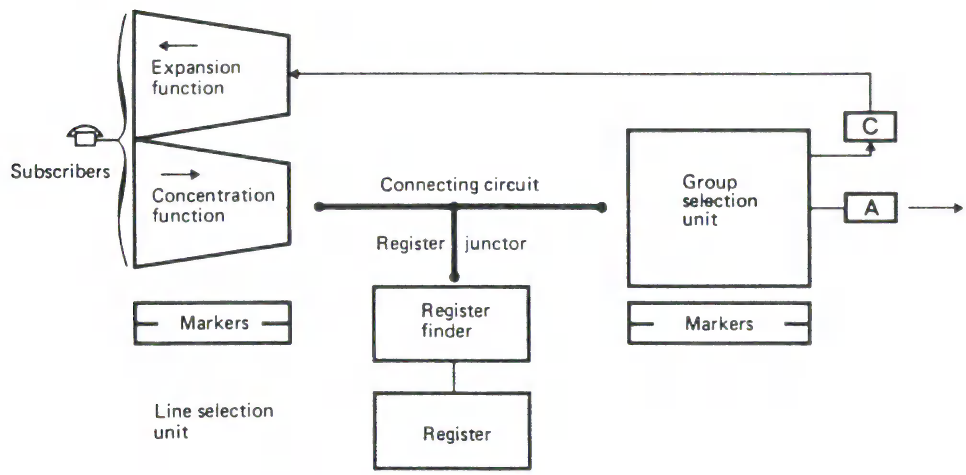

Fig. 2. Typical structure of a crossbar system

and, what is more, SPC, must have been seen by Automatic Electric's engineers as an upheaval in company tradition, not to mention their own experience in switching. Whereas most of the other switching manufacturers had moved gradually from step-by-step technology to one using register control and eventually centralized control of the crossbar type before going on to SPC switching, the same transition did not occur within Automatic Electric, the inexpensive nature of whose products was the fruit of adhering firmly to the same technology for over 70 years. It is easy to understand the considerable difficulties that such a radical change in approach caused GTE and Automatic Electric. A separate new organization, Automatic Electric Laboratories, was created to carry on the new switching research and development.

The engineers at Automatic Electric were, however, perfectly familiar with the principles of using registers and were aware of all the advantages they offered when used in a system for handling the complex operations of analyzing/translating numbering information. Suffice it to recall that it was they, or rather their predecessors, who in the early 1920's had given their British colleagues at Automatic Telephone and Electric of Liverpool the key which enabled them to persuade the British Adminstration to decide to standardize the Strowger system as Britain's switching system: it was Chicago that produced the "Director" device which solved the difficult problems of routing traffic partly dissociated from the subscriber numbering system at several large exchanges in London and other major British cities. Later versions of the Director included billing and calling line identification features and were introduced in the United States and Brazil. They were known as "Strowger Automatic Toll Ticketing (SATT)" equipment and included some electronics.

2.3. The first decision, an easy one but one which was to bear fruit for several decades, was to assign a name to the future electronic system. The name chosen was "EAX" which was to remain unchanged for the entire family of different systems born one after the other at GTE:

- E for Electronic, an attribute of both what the system should be and of the corporation (GTE) in which it was to be produced;
- A for Automatic, recalling both what the exchange itself should be and its affiliation vis-a-vis Automatic Electric;
- X for Exchange, an abbreviation usually more British than American but which was perhaps adopted to symbolize the world market GTE's switching equipment could expect.

2.4. A description of the general principles adopted for designing the EAX was published in 1962 [3]. The architecture was markedly different from that used for the ESS No. 1. It resembled much more the architecture adopted at the time for most crossbar systems (see Fig. 2 taken from Volume I, p. 413).

The influence of engineers who had joined Automatic Electric of Chicago after working in turn for LM Ericsson and later its subsidiary, the North Electric Company, could certainly be identified with the EAX architecture. For instance, there is an undoubted similarity of general architecture between the EAX No. 1 system and the NX-1 system developed by North Electric [5)].

An EAX laboratory mock-up was operational by the end of 1962 and, after various tests and changes, an experimental exchange was commissioned at Portage (Indiana) [6)] towards the end of 1965 to test the reliability of the system and the merits of its design philosophy. The trial period, during which the Portage exchange provided an ordinary telephone service to 600 subscribers, lasted slightly more than one year. These trials were intended to determine the further developments that were needed before the system could be put into normal production and marketed. An EAX plant serving 1,000 subscriber lines and manufactured by GTE's Belgian subsidiary (ATEA) was also brought into service at Hasselt, Belgium, in 1967.

It was then found that since the beginning of the development, a number of factors decisive to both design and the manufacture of an electronic switching system had evolved very quickly. Integrated circuit technology had emerged and the advantages that it offered the telephone industry were obvious on grounds of cost, reliability and speed of operation. Moreover, automatic techniques had been streamlined for developing and producing sub-assemblies using integrated services, thus making for potentially considerable reductions in the cost of manufacturing the switching system.

Lastly, the advantages offered by electronic switching were also clear not only to service operating companies but also to their customers in the United States, i.e. the subscribers. This meant that new facilities, particularly automatic maintenance, had to be inserted into the initial specifications. The design of the EAX No. 1 system was therefore substantially modified and, as a result, the development of the system for mass production took quite some time.

3. The EAX No. 1 put into service in 1972

There thus followed a somewhat lengthy recasting of the system to update its architecture. What was more important, GTE had to develop new manufacturing processes especially for making basic components such as the reed relays for their switching network. It was therefore only in September 1972 that the first EAX No. 1 exchange was brought into service in St. Petersburg (Florida) to serve 8,000 subscribers, followed four months later by a second exchange in Erie (PA).

The EAX No. 1 system was initially installed solely in the United States, first by companies of the GTE Group and, from 1976 onwards, by some of the independents outside the Group. It was also installed abroad after 1976, firstly in Taiwan. GTE then secured a huge contact, the "contract of the century" as banner headlines in the press claimed at the time, for over 500 exchanges and the delivery of almost one million subscriber lines to modernize Iran's telephone network. Unfortunately, however, most of these exchanges were not delivered owing to the events in Iran which led to the severance of relations with the United States.

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5) The latter is described in reference [3] of Chapter V-2, pp. 56–61. The NX-1 system was put into service for the first time at Fayetteville (N.C.) in 1971. Marketed by ITT which had taken over North Electric, it was installed in the United States for independent companies, as well as in Central America and Zambia, and by 1981 was serving slightly more than 600,000 installed lines.

6) Portage is not far from La Porte, Indiana, where the first Strowger step-by-step system was commissioned in 1892 (see Vol. I, Chapter II-2).

4. Architecture of the EAX No. 1 system [4]

The EAX No. 1 system was intended to serve as a terminal local exchange and as a combined local/long distance exchange, i.e. what the Americans called class 5 (End Office) or class 4 (Toll Office) exchanges. An EAX No. 1 exchange had an initial capacity of 4,000–20,000 lines which, in a second version, was raised to 5,000–45,000 lines.

Despite the changes introduced during the development phase, the final architecture of the EAX No. 1 system may be regarded as a fairly direct offshoot of the conventional register crossbar exchanges. It is subdivided into:

- a space-division type switching network;
- a centralized control unit consisting of not only a computer and its associated memories, but also recorders and markers, and devices for the maintenance and operation center.

The switching network itself is divided into two blocks:

- the input/output block for serving subscriber lines in a first 3-stage sub-assembly and, in parallel for serving the incoming junctors or circuits, in a second 1-stage sub-assembly;
- the selector group block consisting of three stages and being the equivalent of the Trunk Link Frame in AT&T systems.

The various stages of the switching network consist of reed relay matrices. These GTE-designed relays, known as "correeds", are actuated and held electrically.

The electronic control operates the switching network through markers which, like the registers, are assigned specifically to one or other of the two blocks of the switching network. The markers have not only to operate the connection matrix relays; they also autonomously carry out the scanning functions for detecting call requests for the different lines or junctors of the switching network block which they are assigned. The markers themselves are integrated-circuit wired logic devices, as are the registers which also include a ferrite-core memory. Only the automatic trouble locating and other maintenance featuring employ the SPC principle.

5. The EAX No. 1, head of a family of GTE systems

Following the EAX No. 1, GTE developed and produced a whole series of SPC systems still known as EAX's but bearing successive serial numbers. First came the EAX No. 2 [5] which, like its elder brother, is a space-division switching system but includes major modificatins vis-a-vis the EAX No. 1, in its switching network and in its control unit. The EAX No. 2 was designed for larger-capacity exchanges than the EAX No. 1 and incorporated more advanced technology, including SPC for call processing.

The EAX No. 2 system was followed by EAX No. 3 and 5, both of which belong to the second generation of SPC systems, i.e. time-division digital systems. The EAX No. 3 is for long-distance transit exchanges and the EAX No. 5 for local and tandem exchanges. The development and general architectural principles of both systems are described in Chapter IX-4. We shall confine ourselves here to mentioning briefly the chronology of the development of the EAX No. 2 system and noting its differences between it and the EAX No. 1.

Development of the EAX No. 2, which started early in 1972, led to the production of a laboratory model in 1975 and to the placing in service of the first exchange at Mahomet, Illinois, in 1977. Another exchange of this type was installed in December 1978 in Mons, Belgium, following production by ATEA (Herentals). The system was also manufactured in Italy in a version developed jointly by GTE (Northlake), ATEA of Belgium and the GTE subsidiary in Milan with a view to exports to international markets [5–7]. By 1982, some 3 million EAX No. 2 lines had been installed throughout the world, first in the United States and Canada but also in Belgium, Panama, Saudi Arabia and Taiwan.

The initial difference between the EAX No. 1 and the EAX No. 2 lies in their switching networks, the EAX No. 2 using not electrically-latched correeds but magnetic latching reeds. The switching network architecture of the EAX No. 2 is based on a number of unit modules which can accommodate both subscriber lines

and trunk circuits or junctors. A single such switching network module consists of six successive stages which both concentrate and grade the speech paths and the traffic carried. One complete connection path through the network thus consists of 12 successive stages, separated into two blocks and connected by junctors.

The EAX No. 2 SPC control unit [6] uses the computers that were developed by GTE for controlling TSPS positions. The first GTE TSPS installations were placed in service at Tampa, Florida, in 1972. In design, it was very similar to the same sort of systems used in the Bell System and manufactured by Western Electric. The scanning, distribution and control functions of the switching network in the EAX No. 2 are performed by a peripheral controller. The computer core memory is divided into the actual program instructions and the data needed for the programs.

As with most successful switching systems, the control portion of the EAX No. 2 was later changed to increase the call attempt capacity of the system. This control was known as the "2B" and was developed by a non-affiliated General Automation Co. [7].

6. A non-SPC GTE system derived from the EAX No. 2

We shall mention in passing the XP 100/1000 system developed and manufactured in Italy by GTE – Telecommunicazioni, S.p.A. of Milan. In the XP 100 version, the system was designed for low-capacity rural local exchanges with up to 600 lines, possibly in transportable containers. The XP 1000 version was intended for much larger exchanges, offering a capacity of up to 45,000 subscriber lines or 9,000 incoming circuits. This system was intended chiefly for the Iranian market.

The XP system used a switching network having reed relays of the type used in the EAX No. 2; it was not a stored-program system, however, its control logic being simply of the wired variety. The discontinuance of supplies to the Iranian network brought the manufacture of the XP 1000 version for large-capacity exchanges to a halt and only a few XP 100 units were ever brought into service.

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CHAPTER V-4

CANADA AND ITS FIRST GENERATION OF SPC EXCHANGES

1. Close links between Canadian and United States telephone services and industries [1].

The telephone industry and the operating of the telephone network in Canada have always been heavily influenced by the United States. Primarily for geographic reasons, which have always alerted Canadian telephone users to the condition and quality of the service offered on the other side of the 4,000-odd miles of their only frontier. To an even larger extent, for historical and economic reasons stemming from the very close links that have existed between the two countries for almost a century in the organization of their telephone services and equipment industries.

The organizational structures of Canada's telephone service operation were described in Volume I (pp. 112–114). Its two major essential characteristics are:

- the vast majority of Canadian subscribers are served by Bell Canada, which holds a monopoly over the telephone systems in Ontario, Quebec and North-West Canada. In the early 1980s, Bell Canada owned 55% of Northern Electric (later renamed Northern Telecom), a company which now ranks second among the telecommunication equipment manufacturers of North America.
- a large proportion of Canadian subscribers live in the Pacific region and are served by Companies of the GTE Group.

Sections 2 and 3 deal with the developments which led Northern Telecom and its research laboratories (BNR) to design and produce the SP-1 system, mainly for the Bell Canada network. Section 4 describes the C1-EAX development by GTE's Canadian subsidiary.

2. The launching in 1965 of Canadian SPC studies (the SP-1 system) [2]

2.1. When Bell Canada was founded in 1880, the American Bell Telephone Company, forerunner of AT & T, provided 25 percent of the equity capital. With various changes within this proportion over time, AT & T's holdings in Bell Canada were about the same by 1930. Then, although the number of AT & T shares remained the same, the proportion of the total dropped as the Bell Canada capital increased from other sources.

One of the consequences of an action launched by the United States Justice Department against AT & T, which was settled out of court in a Consent Decree of 1956, was that long-standing ties between the companies in the Bell System and their Canadian counterparts were deliberately weakened.

During the long period of AT & T's partial ownership of Bell Canada, the Bell System contributed strongly to the Canadian telephone system. According to a 1923 service contract, AT & T "..... furnished engineering assistance to Bell Canada and exchanged data and technical advice in connection with the construction, maintenance, repair and operation of the plant". This contract, continuing more or less under the same terms for more than 50 years, was only terminated on June 30, 1975.

2.2. Western Electric owned about half of the shares of the capital of Northern Electric (formed in 1914). In 1956, following the United States Consent Decree, Western Electric disposed completely of its Northern Electric stock.

Bell Canada and Northern Electric had realized that the flow of technological information on which they had relied from AT & T and Western Electric would dry up and that some form of R & D activity would be vital to serve the Canadian telephone industry. After the establishment of a R & D laboratories organization in 1958 as part of Northern Electric, Bell-Northern Research (BNR) was established as a separate corporation in 1971, under the leadership of Dr. D.A. Chisholm.

After the success of the AT & T No. 1 ESS in the United States, Bell Canada had quickly recognized the potential advantages of SPC switching. Northern Electric had been asked to provide a No. 1 ESS SPC installation in Montreal for the World Expo. in 1967. To do this, Northern had to learn the principles of this SPC system and how to manufacture, install, test and maintain it. Eventually Bell Canada installed eight No. 1 ESS exchanges.

2.3. However, the design of the AT & T No. 1 ESS did not meet the size range requirements for Canada. It was designed for large installations such as were common in the United States, and would not be economical for small entities such as Canadian rural towns with only 1,000 to 5,000 subscriber lines.

Feasibility studies were started in Bell-Northern Research and Bell Canada for a new SPC system tailored both to the scale of the Canadian manufacture and to the needs of Bell Canada and of other Canadian telephone companies. The feasibility study conclusions (1967) were that the new system:
- should be based on the concept of stored program control;
- should be economical in small to medium applications, but also capable of expansion into large installations;
- should be comparable in cost to the existing crossbar systems;
- should be simple and economical to manufacture, install, and maintain.

To adapt to various requirements of local service, long distance, special operator services, etc., a family of switching systems using essentially the same hardware was recommended. In conjunction with this study, BNR, after examining the possibility of adopting AT & T's No. 2 ESS, launched the SP-1 project in 1964. The family concept, size and features of each system were determined as a result of direct consultation with the various Canadian telephone operating administrations.

3.2 The SP-1 system [3]

3.1. The aim of the SP-1 system was to produce an exchange with a nominal range capacity of 2,000 to 10,000 lines, expandable later to 20,000.

The design objectives for the system could be defined by three key words: "flexibility, simplicity and economy":
- flexibility was ensured by centralized SPC control;
- simplicity was achieved by adopting a crossbar switching network with sleeve lead control: for economy and compactness the crossbar component used was a miniature crossbar switch, known as Minibar. The Minibar's sleeve lead would permit distributed control of the switching network, which meant that the control's memory capacity could be limited because switching network status was independent of mapping in memory;
- economy was secured mainly by using the existing standard crossbar components with wired logic control.

The other basic features of the SP-1 system were those then considered standard: duplication of the central control to ensure reliability, maximum use of integrated circuits in the central control complex, an elaborate "defense" program to diagnose faults and simplify maintenance operations.

3.2. The SP-1 system was divided into three sub-systems: the switching network, the peripheral equipment and the central control.

The minibars making up the *switching network* provided a 200-point six-wire switch (10×20 array). The architecture of the switching network derived directly from the crossbar systems was similar to the one of AT&T ESS No. 1.

The *peripheral equipment* consisted of scanners, markers, signal distributors, and a bus system:

- the scanners were responsible for detecting service requests and supervising calls in progress.
- the function of the markers was to set up the speech path through the switching network by operating select and hold magnets on the minibar switches.
- a signal distributor had the task of operating and releasing electrically latching relays in various items of equipment under the direction of the central control. Essentially it was a buffer between the high-speed central control and the relatively slow relays.
- the bus system provided the means of communication to and from peripheral units.

The *central control*, which was duplicated, was divided into three sub-units: a central processing unit (CPU), a program store and a call store. The CPU acted as executive and scheduler, controlling the actions of all other units in the system by causing them to execute, one at a time, instructions from the program store. The program store contained the instructions required to process calls and administer the exchange and included also its data base. The call store was the "scratch pad" memory which handled all the temporary information required during the processing of a call.

In accordance with the AT&T practice, there was a generic program for all SP-1 exchanges of the same type, while each exchange had its own data base, which was incorporated in the program store.

3.3. In 1968 the SP-1 system was tested in service at the Britannia exchange in the western Ottawa suburbs with perfect satisfactory results. The first SP-1 exchange put into service was in the town of Aylmer, Quebec, in 1971. A new version of the SP-1 system with four-wire switching for a transit exchange was developed in 1969, the aim being to produce transit exchanges with a capacity ranging from 200 to 4,000 incoming trunk circuits. After laboratory work and in-service tests, the first four-wire SP-1 system was put into service at Thunder Bay, Ontario, in June 1974 (about 1,000 incoming circuits). Following the example of AT&T, some transit exchanges were supplied with consoles providing operator services (Traffic Operator Position System) (TOPS) [5]. The first of the exchanges equipped with TOPS consoles was installed at Junot, Alaska (April 1975) [4].

In 1975, four years after the first SP-1 installation, there were 39 two-wire SP-1 local exchanges and 7 Centrex SP-1 units in service in North America. There were also 5 SP-1 transit exchanges and 3 TOPS units. Bv 1979 the total shipments were 219 offices with 2.9 million lines and more than 1500 TOPS positions. As with most successful systems, a processor with greater capability was made available in 1981. The improved version of the system was known as the SP-1E.

4. The C1-EAX [6] – another Canadian contribution

While GTE's principal laboratories in the United States were struggling to develop large Electronic Automatic Exchanges (see Chapter V-3), their Canadian subsidiary in Brockville came up with their own electronic switching system development which they called the C1-EAX, where C1 stood for the first "Canadian" switch. (The prefix type of coding was also used for other non-US developments of GTE. For example the early designs from Belgium were known as the A1 and A2-EAX.)

The C1-EAX development initially was for the GTE Canadian market. The first installation was in Whonock, British Columbia, in 1967. By 1970 the marketing strategy had changed and sales were made outside of Canada to independent telephone companies in the United States, to the Philippines, Dominican Republic, Haiti and Mexico.

The system used "Dimond" rings (see Chapter II-1) for storing the macro action-translator type program. Later versions of the system, known as PL2, used EPROMs to store the macro program. The network element of the system was a 1×100 crosspoint coupler switch that was used in earlier GTE electromechanical switching systems and PBXs. This switch was developed originally by the Leich Switchboard Company, acquired by GTE in the early 1950s.

More than 110 C1-EAX offices were installed serving a total of about 160,000 lines.

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CHAPTER V-5

JAPAN AND ITS FIRST GENERATION OF SPC EXCHANGES

1. Japanese structures: NTT and KDD. The prodigious growth of Japanese telecommunications through five-year plans

Following the establishment of new operating structures after the Second World War, with the creation:

- in 1952 of NTT (Nippon Telegraph and Telephone), a government owned and independently operated corporation supplying Japan's domestic requirements, and
- in 1953 of KDD (Kokusai Denshin Denwai), a semi-governmental organization covering international services,

Japanese telecommunications underwent a phase of prodigious growth, which gave Japan one of the largest telephone networks in the world, second in size only to that of the United States, with a total of 44 million direct exchange "mainlines" in 1985.

Throughout the various stages of this expansion, which was punctuated by a succession of five-year development plans (15.5 million new telephones between 1968 and 1972 and more than 22 million between 1973 and 1977), the history of electronic switching systems in Japan is similar to that of the Japanese economic progress, and NTT and the major telecommunication manufacturers [1] have put a great deal of effort into extending the telephone systems over the whole of the Japanese islands.

[1] The "big four" Japanese manufacturers of telecommunication equipment, i.e. (in alphabetical order): FUJITSU, HITACHI, NEC (Nippon Electric Company), OKI.

2. 1954–1964: beginnings of Japanese research on electronic switching systems

See Chapter II-5, under section 1 of this Chapter.

3. The D-10 system [1,2]

In June 1972, the first Japanese SPC system, the D-10, was brought into service by NTT at the major Japanese metropolitan areas of Ginza in Tokyo (Fig. 1), Nagoya, Osaka. These offices were installed by the major "big four" Japanese switching manufacturing companies (NEC, Hitachi, OKI, Fujitsu) in the same year.

These operations represented the culmination of nearly ten years of long and painstaking research (Fig. 2), which had begun in 1963 when a contract was signed between the "big four" switching manufacturing companies and NTT research departments (Electrical Communications Laboratories or ECL, at Musashino) to set up an SPC system as a joint development project.

Research begun in 1964 and led to the production of a laboratory prototype, known as DEX-1 [3]. It used ferreed relays matrices in the switching network, transistor logic for the processor and, for its memories, a temporary ferrite-core memory and a semipermanent "metal card" memory investigated by J. Yamato in the NTT Laboratories.

Meanwhile NTT had developed with NEC another prototype using PCM-based time-division switching and technically completely satisfying. The purpose of this prototype, known as DEX-T1 [5], was to indicate whether it was

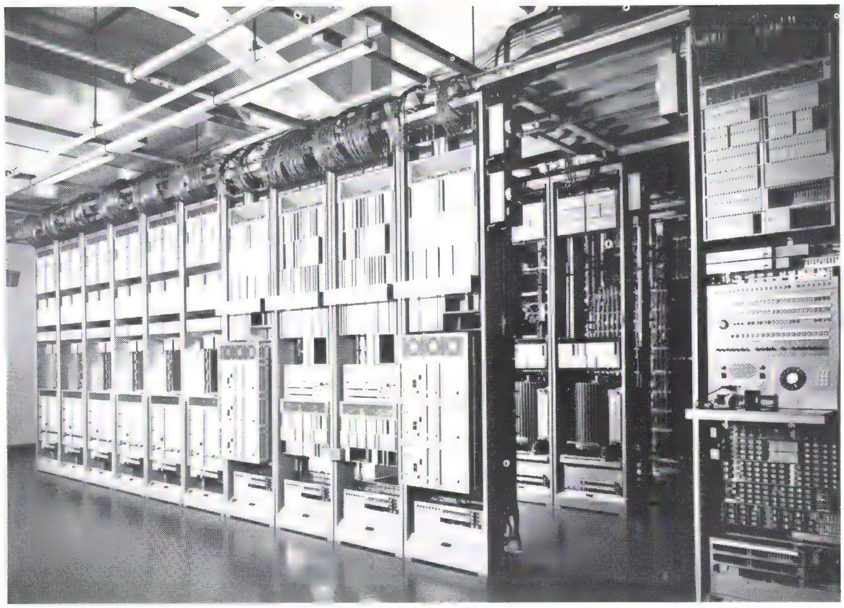

Figure 1. The first Japanese SPC system in service in June 1972 at the Ginza office (from [4]).

preferable at that time to move towards PCM time-division switching or to rely on space-division like that adopted for the ESS No. 1 system. After comparative tests of the DEX-1 and DEX-T1, in 1969 NTT opted for space-division switching. A DEX-2 system of the latter type [6] then produced and submitted to exhaustive field tests which ended in 1970. The main characteristics of

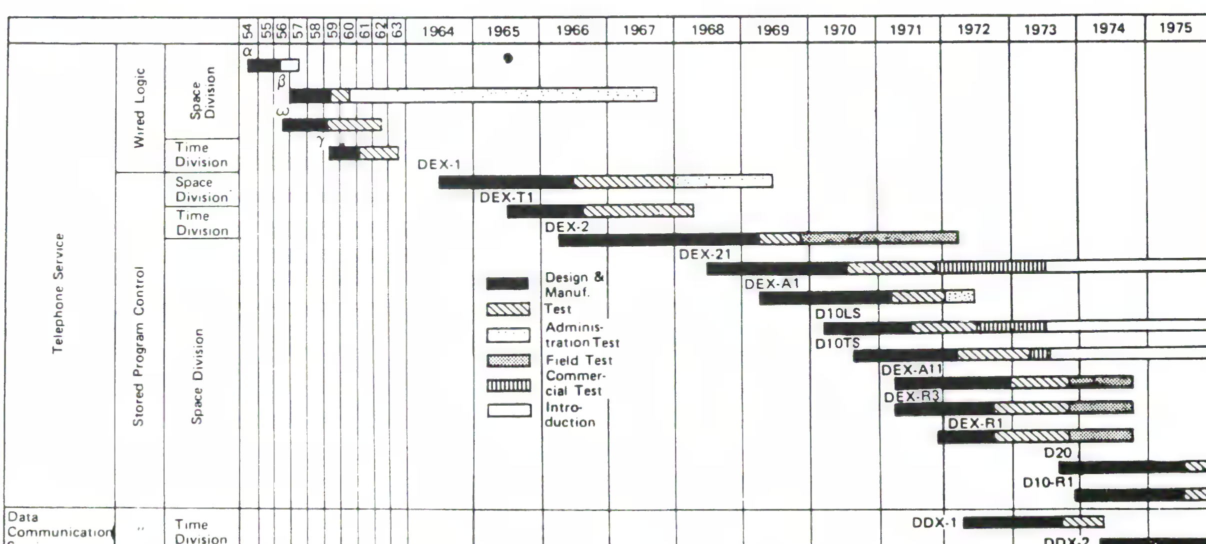

Figure 2. Development history of the Japanese switching systems between 1954 and 1975 (from [4]).

the DEX-2 system were substantially different from those of the DEX-1, in particular with respect to the use of:

- mechanical latching type mini-crossbars, invented by M. Takamura in the NTT Laboratories, for the switching network;
- integrated circuits for the processor logic;
- more elaborate programming, making more extensive use of "macro" instructions for switching functions and using the concept of state transition diagrams originally proposed by K. Ibuki in the NTT Laboratories.

The DEX-2 was brought into service at the Ushigome exchange in Tokyo in 1969 and proved to be of even better quality and more reliable than had been expected. Further improvements were made in the system and led to the DEX-21 [7]. This system employed the duplex ("2n") redundancy principle for magnetic drum memories. The operation of logic circuits and access to memories (ferrite-core main memory) were speeded up and the switching network was altered to achieve substantial savings in the number of crosspoints.

Excellent results were obtained at the end of 1971 with the DEX-21 system introduced at Kasumigaseki exchange, Tokyo. The exchange, connected with the existing nationwide network, offered a service to 2,000 NTT headquarters subscribers. These results led to the adoption of the system by NTT as standard equipment for its main local exchanges. The system, then renamed D-10 by NTT, was equipped with various extra functions and facilities to meet the requirement of a very broad and diversified range of users. Detailed specifications of the D-10 system were then laid down by NTT to ensure that all the equipment produced by different suppliers was perfectly compatible.

4. Behind the code D-10, a whole family of special applications

4.1. The name D-10 applies in fact to a whole family of different models of exchanges:

- firstly, local exchanges (known as LS) of large or very large capacity: the nominal capacity, originally 65,000 subscribers lines (189k BHCAs), was increased to 180,000 lines (302k BHCAs) in a new version introduced in 1978;
- combined local and tandem exchanges (known as TLS) for local transit in a large town;
- trunk transit exchanges (known as TS) with four-wire switching in the switching network [2];
- finally, a model known as D-10-R1 [8] intended for local exchanges smaller than the LS, to operate as the satellite of a D-10 exchange under the remote control of its processor. This model had been under study by NTT for a long time [9]. Research began back in 1966 and led to a prototype known as DEX-R1 [10], followed by two years of comparative tests of two competing versions in operation, which finally culminated in the D-10-R1. Exchanges of this type were brought into service from 1977 onwards.

4.2. Production of D-10 exchanges was very soon in full swing. Five years after the first models were delivered in 1972, there were already 165 of the LS type (local service). By 1986, the number of exchanges from the D-10 family providing local service was more than 750 serving about 9.6 million lines.

According to 1977 Japanese figures supplied to the CCITT for the work of its GAS 6 (preparation of a "Manual on the choice of switching systems" [11]), 51% of NTT subscriber lines were served by exchanges with a capacity of more than 10,000 lines (exchanges partly of the C-400 crossbar type, partly of the D-10 type). This majority population of Japanese subscribers was precisely the group for which the D-10 system was intended.

[2] The Japanese common channel signaling system,a national version of the CCITT type No. 6, was brought into operation in 1973 between D-10 trunk exchanges in Tokyo and Osaka. And CCITT type No. 7 system, for which S. Kano in the NTT Laboratories was an active contributor to CCITT standardization, was brought into operation in 1982 between D-10 trunk exchanges in major metropolitan areas.

Unlike the introduction of electronic switching systems in other markets, the Japanese industry was not able initially to realize the considerable savings this technology offered. Much opposition was encountered from labor unions that insisted upon the same number of personnel in production of electronic exchanges as in crossbar exchanges.

The D-10 system was also provided with features for operator services with cordless switchboards, land mobile (cellular) service and coastal maritime service.

5. Software of the D-10 family [12]

5.1. The software of a D-10 exchange was based on:

- a generic program corresponding to the type of exchange and facilities planned for it (e.g for an exchange of the CENTREX type),
- a data base containing the data specific to the exchange.

To produce the D10 software and provide each particular exchange with its software, NTT set up software centers, with the following functions:

- program production (development)
- program modification and extension (maintenance)
- office data production (for new exchange)
- office data modification and additions (for growth)
- production (mass production) of copies of the system file.

5.2. A call processing state-transition diagram has been used in the D-10 software system to manage call processing states. The diagram gave both the logical state of a call and the state of each trunk/service circuit on the same diagram.

In 1977, NTT improved the D-10 software system in order to increase its flexibility and reduce maintenance and administration costs. The result was the D100B software system which was put into commercial use in 1981. This new software version is composed of Function Modules and described in CCITT High Level Language (CHILL) subsets [3]. A hierarchical state transition diagram is also used in the D100B software system.

6. D-20 and D-30 systems, derived from the D-10 system and intended for smaller exchanges

6.1. The D-10-R1 exchanges, with relatively limited capacity, were intended to serve subscribers in major cities already provided with D-10 exchanges. NTT wanted to have also SPC exchanges with a capacity of some 15,000 lines for the local networks of medium-size towns outside the metropolitan areas. The aim was to have a modern SPC system competitive in price with the C-460 crossbar exchanges while providing subscribers with the new facilities offered by the D-10.

This was the D.20 system, which was first put into service at Hakone in 1976 [13]. Research on the D-20 system had begun back in 1969 and had been carried on concurrently with work in the D-10-R1 system. Successive prototypes (DEX A1 [14], DEX-A11 [15]) were developed in 1971 and 1973 and were tested for two years in actual operation before the system was standardized and finally baptized the D-20.

A younger brother of the D-10, the D-20 was not merely a sub-version or variant, as is shown by the fact that it was given a name of its own. In the process of developing the D-20, special attention was given to the design of its central processor. It is a familiar fact that although the cost of the switching network rises linearly with the number of lines served, the cost of a processor is virtually independent of the exchange size and capacity. This meant that SPC switching was at a marked disadvantage economically for exchanges of medium or small capacity (at the time in question, of course, before microprocessors came on the scene).

[3] K. Maruyama in the NTT Laboratories, leader for the use of the CHILL language in this new software version, had been a very active contributor in the framing of the CCITT recommendations on CHILL.

To arrive at an economic processor, the D-20 made substantial use of auxiliary memories made up of magnetic drums which were relatively low-cost units, for call processing as well as for other functions. The main memory systematically drew on programs or subprograms contained in these auxiliary memories. The storage capacity needed had been substantially reduced through the adoption of wired logic in different parts of the system.

In an initial version of the D-20, the switching matrices were minicrossbar switches. By 1979 the designers of the D10 family realized the advantages of manufacturing and space savings of sealed contact switches with internal magnetic latching. Furthermore the "big four" manufacturers discovered that to sell SPC switching systems in the international market they needed a non-crossbar technology. As a result, new switching network devices called "Sealed Multicontact Matrices" (SMM) were included in newer versions of the D10 family of switches. At the same time a new high-speed processor was deployed. The nominal capacity of the D-20, originally 16,000 lines (19.3k BHCAs), was increased to 24,000 lines (32.5k BHCAs) in the post-1979 versions [16].

6.2. The advent of microprocessors towards the end of the 1970s finally enabled NTT to complete the range of its SPC space-division switching systems with a third type, duly numbered the D-30 [17]. Unlike its elder brothers, the D-30 was put into operation in 1979 in Yokohama after scarcely more than a year's research. It consists of a microprocessor (duplicated) and a switching network using the same components as the D-20 version which was its contemporary. The nominal capacity limit of the D-30 is 2,000 subscriber lines.

7. Growth of crossbar and SPC systems respectively

It is interesting to note that it was between 1978 and 1979 that in Japan the economic balance swung in favor of producing SPC systems, seven years after they were first introduced [18]. (It was of course not until some years later that the same swing occurred in the NTT's subscriber line population, owing in particular to the existence of a considerable number of relatively new crossbar exchanges).

8. Other Japanese space-division SPC switching systems

8.1. Besides their production of D10 and D20 systems for the domestic market and the NTT needs, the Japanese manufacturers began during the 1970s to develop and manufacture SPC space-division systems for markets outside of Japan. As mentioned above, this meant including in their systems sealed contact relay matrices. Each manufacturer entering this market came up with a different version of switch matrix. However, their export activities during this period were still limited when referred to what it would be during the 1980s for the time-division systems that they were studying and developing in the late-1970s with specific objectives of export.

Among the more important SPC space-division Japanese systems developed and manufactured in the 1970s for export, we can mention:

- the FETEX systems (space-division versions) of Fujitsu, with different types, numbered Fetex 20 (using remreeds, called "memoreeds"), Fetex 100 (using minicrossbar switches), with exchanges installed first in Singapore in April 1978, followed by offices in Jordan and Hong Kong [4].
- the systems of Nippon Electric Company (NEC):
  a) ND10 and ND20 for local/tandem exchanges, with installations in more than ten countries, especially in America: in Latin America but also in the USA for the market

[4] The next number in the series of the Fetex systems is the Fetex 150, a time-division system that appeared in 1982 (see Chapter IX-8, section 5.2). PBXs ommercialized by Fujitsu on export markets are also labelled with the same brandmark and as Fetex 400.

offered by the "Independent companies" with the cutover of their first central office in Connecticut in April 1977. In Latin America local manufacture was introduced into Argentina by NEC.
There was the ND10A version with minicrossbar switches and the ND10B version with what NEC called minireeds. There were also smaller versions of the systems, which like the D20 series were designated ND20.

b) NXE-10 and NXE-20 for transit international exchanges, (NEX-10 installed in Singapore in 1980 and NEX-20 installed in Pakistan in 1980).

8.2. KDD, the Japanese operator of the international telephone service, had in the 1970 very specific requirements for its international exchange. Most of the calls from the domestic NTT network required the assistance of operators due to language difficulties between the Japanese caller and the called party. International DDD (direct distance dialing) service from most of the Japanese local exchanges was not yet available and a semi-automatic service with outgoing international operators had therefore to be provided for a large majority of the international traffic. With the recent opening of transcontinental submarine cables and satellite circuits, the demand for international calls was very high and growing at an exponential rate.

Following a KDX0 prototype designed in the early-1970s by NEC [19], this company in 1977 provided KDD with the "XE1" system, an "unique-type exchange". It served 9000 trunks/international circuits, 500 consoles of operators' cordless positions having at their disposal voice response announcements provided by magnetic drums.

The XE1 exchange had two separate switching networks: one for the trunks and circuits, the other serving the positions and switchboards. Each of these networks had its own SPC control. The elements of the switching networks were 8×8 matrices of miniature crossbar switches [20,21].

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CHAPTER V-6

UNITED KINGDOM (1960–1980). THE SPACE-DIVISION TXE 2 AND TXE 4 SYSTEMS

1. Finding an Alternative to Highgate Wood

1.1. Although the Highgate Wood exchange had been the main objective of the "Joint Electronic Research Committee" (JERC) set up in 1956 (see Chapter II-5, under 3.2), each of the JERC's industrial partners was conducting its own research on electronic switching in parallel with JERC. There were no less than five such studies being pursued in the early 1960s, three relating to time-division switching and two to space-division switching. As was the case elsewhere in Europe, one of the latter concerned a switching network with crosspoints consisting of PN/PN components. Different types of component, particularly memories (magnetic drum/magnetostriction delay line/temporary ferrite core memories), were tested in all five laboratory models which, incidentally, were all of very small capacity (30–100 subscriber lines). The diversity of the equipment incorporated more or less matched that used in the Highgate Wood exchange.

One of these 1960 prototypes – the reed-relay space-division switching system developed by AEI and commissioned at its Blackheath laboratories – was to set the trend in Britain following the Highgate Wood experiment.

2. New trends in British research: systems using a Reed-relay switching network

2.1. Options of the GPO

One of the basic conclusions drawn from the Highgate Wood experiment was that, at least for many years to come, electronic switching should be based on a space-division principle.

The requirements as seen by the GPO were fairly clear [1]. A system capable of taking over from the Strowger step-by-step system had to be found fairly quickly following the disappointment over the electronic type of switching initially envisaged. Contrary to the fashion prevailing in mainland Europe (with the exception of the FRG), the GPO was reluctant to adopt a crossbar system. It considered that, in the state-of-the-art in those days, crossbar could only serve as an interim system pending the introduction of Britain's future electronic system. The special "facilities" being promoted as one of the main advantages of SPC systems were of little interest to either the GPO or its customers. Public opinion was clamoring for ready access to the network at the cheapest possible price. Other "facilities" were seen as a totally superfluous luxury.

2.2. Disputes between partisans of wired-logic and SPC

SPC switching had only partial support in the United Kingdom. Research for an SPC system required considerable industrial investment which the then fragmented British switching industry was reluctant to commit itself to. In addition, the same industrialists took a dim view of all the difficulties which would radically change their manufacturing methods and would entail for them employment problems arising from the new required skills of their labor force and, still more

critical, of the engineering staff at their research and development centers.

Lastly, and this did much to put Britain against SPC systems, switching based on the American model seemed in the United Kingdom to be inappropriate for the medium and small capacity exchanges primarily needed by the GPO. The high cost of the duplicated processors for an SPC system and of preparing their programs was considered justified only for very large capacity exchanges.

The dispute between advocates of wired-logic as opposed to SPC systems went on for a long time in the United Kingdom and the technical literature of the time abounded in contentious articles for or against one or the other [2,3]. The most impressive traces of this controversy are to be found in the Proceedings of the IEE, particularly in [4] which reports on a discussion held as late as March 1972 in which the GPO research departments came out strongly for wired logic but met stiff opposition from many representatives of Britain's industrial switching groups.

The controversy was fueled by echos reaching the United Kingdom from other countries, and particularly from Australia which had formerly been dependent on British technology. From the late 1950s onwards, Australia had moved away from the step-by-step model system used in the United Kingdom and had opted for crossbar systems. By the late 1960s, a further trend became apparent and Australia started to move towards SPC systems, and articles published in Australian technical literature (e.g. [5]) and promoting the virtues of SPC systems were bound to have an impact in the United Kingdom.

2.3. *Decisions taken in 1963*

In accordance with the GPO policy, there was in 1963 a clear tendency in favor of systems using a form of electronic wired logic rather than stored program logic [1] and space-division switching, with a switching network based on the components newly developed in the United States, i.e. reed relays.

Research into such systems was entrusted to ETL, GEC and AEI [2]. Under American licenses, Britain started producing reed relays and these were used in the experimental systems developed by each of the three industrial groups mentioned hereafter with the result that the following three exchanges were put into service:

- in 1965, Leamington (ETL) and Peterborough (GEC): 200-line units, the forerunners of what was later to become the TXE 2 system;
- in 1966, Leighton Buzzard (AEI): this exchange served 2000 lines in what was known as the TXE 1 system [3] of which a second development produced the short-lived TXE 3 system.

3. Choice of the TXE 2 and TXE 4 systems: a long and difficult process

3.1. The Reed Electronic Project Executive Board, a joint committee formed by the GPO and its industrial partners, had been given the task of evaluating the merits of each of the three exchange models mentioned. When it completed its assessment, the GPO adopted two systems, both using electrically held relay matrices and designated by the acronym TXE (Telephone Exchange Electronic):

- the TXE 2, a system for use in small or even very small capacity exchanges;
- the TXE 4, a system intended for large capacity exchanges.

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[1] One of the authors, AEJ, considers these systems to be of the "action translator" type.

[2] ETL = Ericsson Telephones Ltd, AEI = Associated Electrical Industries Ltd, GEC = The General Electric Co Ltd, ATE = Automatic Telephone and Electric Ltd.

[3] The TXE 1 was also developed into a new SPC version, also researched by AEI, which became known as the TXE 3 system and was installed by AEI at the 9600-line Royal Exchange in London in 1968. When AEI was taken over by GEC in 1972 the TXE 3 was dropped and superseded by the TXE 4. The Leighton Buzzard prototype was also known under its AEI initials "REX" (Reed Electronic Exchange). After the GEC take over, a REX version was marketed abroad as a 100–1000-line small exchange.

3.2. The process leading up to the GPO's choice of these two systems was extremely long, particularly in the case of the TXE 4 which obtained official blessing as a replacement of Strowger local exchanges only in 1973.

All this shillyshallying was a direct reflection of Britains's rigid structures at the time, ones which conditioned all relations between industry, the labour unions, the GPO and the political authorities.

3.3. The British switching industry was somewhat fragmented in the early 1960s and consisted of no less than five companies, most of them much smaller than their counterparts in other countries. Mergers resulted later in the same decade, though not without a number of technical upheavals and repercussions.

Another feature of the industry was its extraordinarily corporatist nature in its relations with the GPO, a type of relationship that management schools qualify as "symbiotic". All orders from the GPO were placed under a Bulk Supply Agreement whereby they were confined to only five British companies and shared between them in a virtually immutable manner. This quota system, sometimes known as the "Ring", dated from the 1920s and, in the case of switching equipment, was not officially abolished until 1969. The counterpart to this *de facto* cartel was the GPO constraint to restrict its equipment orders only to the models it had standardized in conjunction with the RING partners.

3.4. The GPO's only switching system was the Strowger and there was no other type of exchange in the British network in the 1960s. British industry had to go on churning out Strowger exchanges for its main client, the GPO, even though this technology was regarded by experts as obsolete and in the long term doomed.

Meanwhile, the demand for automatic exchanges using crossbar systems was strengthening in foreign markets. Consequently, British industry was to lose its traditional overseas customers one after another. Could it go on waiting indefinitely for the future electronic system which had been constantly promised and expected but never seemed to come? Should not the United Kingdom turn to the manufacture of crossbar systems like everyone else except the Germany (FRG)? Should not the GPO at last accept and itself introduce crossbar exchanges in its network, if only to justify the investment needed to produce them for export?

3.5. In order to allay bitter criticism of the telephone service, particularly about the difficulties of receiving the privilege of becoming a subscriber to it, the British Parliament voted in the Post Office Bill of 1969 to modernize the structure of the GPO. In point of fact, the terms of reference given to it contained no reference to any British industrial policy that could be implemented through GPO orders. The only duties assigned to the GPO with regard to the telephone service were:

"to exercise its powers to meet the social, industrial, and commercial needs of the British Islands.. and, in particular, to provide throughout those Islands.. such telephone services to satisfy all reasonable demands for them."

Although known about well before the Bill was enacted, this highly limitative and quaintly worded mandate did not prevent those industrialists who favored the crossbar system from extracting a decision from the GPO in 1967–1968 for introducing crossbar systems into its own network, if only as a temporary expedient. With the electronic systems then gestating, two crossbar local systems were thus competing:

- a British-designed system developed at Liverpool by ATE, which after Plessey took that company over, became the Plessey 5005 system [4];
- the Pentaconta system of the ITT group, in a technology to which STC (Standard Telephone and Cables Ltd), a member of this group, had access [5].

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[4] A system designated in the GPO terminology as the TXK 1 (local system) and TXK 2 (international gateway system). See Vol. 1, pp. 445–449.

[5] A system designated in the GPO terminology as the TXK 3 for local exchanges and TXK 4 for trunk exchanges. (See Vol. I, p. 444.). Later, in 1977–1979, two international gateway systems designed by LM Ericsson and produced for the GPO in the United Kingdom through Thorn were also designated by the prefix TXK in the GPO terminology: systems TXK5 (crossbar) and TXK6 (codebar).

In 1968, GEC also joined the camp of crossbar supporters and secured a license from Plessey to manufacture the 5005 system.

3.6. There were lively disputes and struggles for influence in 1971 and 1972 between:
- those who favored crossbar systems and already anticipated their combination with SPC as some other countries were starting to do, and
- the supporters, including the GPO, of systems based on reed relay switching networks.

In 1972, the matter reached the Prime Minister's Cabinet Office. Ms. J. Hills [6] describes with wry British humor how perplexing it must have been for members of the Cabinet meeting at Downing Street to be faced with so technological a choice. With a wisdom worthy of Solomon, they decided on a cleverly balanced dosage of credits to the partisans of both camps.

3.7. Meanwhile, those who favored the second – the reed-relay option – lost some of their troops. The wave of mergers among Britain's switching industry which in the early 1960s had led to the takeover by Plessey of ETL and ATE (of Liverpool) culminated in the takeover of AEI in 1969, this time by GEC. AEI was firmly committed to the partisans of reed-relay systems; it had itself researched the TXE 1 and TXE 3 systems (see footnote 3 above) and, indeed, it was the cost of that research which ushered in the financial difficulties which eventually led to its being taken over. Thus, at the time AEI ceased to exist, all research on the TXE 1 and TXE 3 systems was abandoned and the teams which AEI had committed to such research were partially dismantled.

Accordingly, by the early 1970s, only the TXE 2 and the TXE 4 were still in the running as electronic systems for installation in the United Kingdom.

4. Deployment of the TXE 2 and TXE 4 systems

4.1. So, after all the wrangling of the 1960s, the only electronic local exchanges installed in the United Kingdom in the 1970s and early 1980s belonged to the TXE 2 and TXE 4 families of systems.

4.1.1. After its initial entry into service at Ambergate late in 1966, the TXE 2 was mass produced by all the British manufacturers from 1969 onwards and many of them were installed throughout the United Kingdom: there were over 1200 such exchanges serving some 2 million subscriber lines there by 1981.

4.1.2. By 1983 about 350 TXE 4 exchanges (representing in excess of 4 million lines) had been installed both to replace the aging Strowgers and to meet the growing demand from urban subscribers.

The first TXE 4 was installed at the Tudor Exchange in North London in 1969 and for the next two years permitted trials under real service conditions. However, the system was not placed into production industrially until 1975 or 1976, when the first mass-produced model was installed in Birmingham. Manufacture of the TXE 4 equipment approved by the GPO was shared between STC (which had been responsible for developing its control system and accounted for most of the production), Plessey and GEC.

4.2. We speak of the TXE 2 and TXE 4 families of systems because, although they had been standardized, the system designs did not remain static but were produced in successive versions, the more important and best known of which were:
- the PENTEX version of the TXE 2, developed by Plessey for export to some 15 countries: this had a considerably higher capacity than the TXE 2 and included post-1965 technology components in its register and call-control areas;
- the TXE 4A system developed by STC from 1976 and marketed in 1980: this incorporated a total recasting of the electronic hardware which made up the control logic of the TXE4.

5. Technological features common to the TXE 2 and TXE 4 systems

5.1. Following the disappointments of the time-division systems at Highgate Wood, which although novel proved to be a fiasco in its day, the British adopted an extremely cautious approach to electronic switching.

5.2. The architecture of the TXE 2 and TXE 4 – with its indirect control system based on registers – was similar to that which had made crossbar systems so successful outside the United Kingdom.

5.3. In Britain's technological history, the TXE 2 and TXE 4 systems marked a final break with the step-by-step approach in that their switching networks used conjugate selection. The descriptions of them, in special publications intended largely for British readers unfamiliar with the conjugate selection concept, dwelt at length on the advantages of this new mode of operation: "The available paths in the switching network are found by interrogators and markers; the best path is selected according to predetermined rules and that path is marked. The selection is therefore an overall path selection and not a stage-by-stage selection where a call may become committed to a path which leads to a dead end ... The two ends of a required connection through the switching network are determined by their equipment number".

5.4. Instead of switching matrices made up of crossbars, the TXE 2 and TXE 4 had matrices consisting of units with a small number of associated reed relays. These switched four wires at each crosspoint contact: two speech wires, a path holding wire and a meter wire [6)]. The configuration of a switching network based on reed relay matrices is quite similar to that of its crossbar counterpart. The only difference is that the switching network in the former requires a greater number of stages made up of smaller switching matrices. In-depth cost studies conducted in the 1960s had demonstrated that an economic optimum could be obtained by the use of small switching matrices. For the same grade of service this afforded a reduction in the number of crosspoint contacts needed in an exchange, and therefore in the cost of the exchange itself.

The small size of the switching matrices – usually of the 5×5 unit type – each consisting of four reed contacts in the strip (one contact for each of the four wires switched), offered another advantage, one which had been of major concern to the designers of the TXE 4 and even more to those of the TXE 2: it permitted an easy growth of the number of subscriber lines attached to an exchange, a basic feature of the Strowger exchanges by which the British Administration set great store.

5.5. The central organ, the logic of which controls the operation of the crosspoint contacts via markers, might have been called the system's "processor" had the word not been alien to British terminology of the day. In fact it came into being only in the late 1970s in connection with the TXE 4 and its development towards the TXE 4A. The generic term used until then had been "control unit".

5.6. At the time TXE 2 and TXE 4 were initially developed, only single circuit elements using discrete components were thought sufficiently proven to be incorporated into the design of their control unit. Their logic was a wired one. Use of the SPC technique was considered inappropriate for the repetitive function of establishing the paths through the switching network and this function was left to simple wired logic markers associated with the wiring modules. This was especially the case for the TXE 2 exchanges, the task of which was basically to establish simple calls which did not require sophisticated facilities or special treatment.

[6)] "Although electronic metering using magnetic drums has been under consideration by the GPO for a great many years, its use was rejected in favor of traditional ratchet-type meters operated via the 4th crosspoint contact specifically provided for the purpose" [7].

The choice of wired logic and the antipathy of the TXE 2 and TXE 4 technology to SPC design may be explained by:

- the marked preference of the research departments of the GPO, an administration which was the main if not the only customer for the public exchanges being developed;
- the many lengthy delays that occurred prior to the system mass-production stage and the fact that their initial design dated from the mid-1960s, i.e. a time when SPC exchanges were only just starting to be mass produced in the United States;
- the misgivings of British manufacturers. It was already enough for them to have to revolutionize their switching equipment production methods and switch from mechanical workshops to factories for mounting electronic components on printed circuit boards (PCBs). The assimilation of large numbers of new skills in computer programming for SPC systems entailed an outlay which seemed quite superfluous to the managers of so hidebound and inward-looking an industry;
- lastly, and this is a purely technological argument: the very small memory capacities of the storage devices selected in the system design.

5.7. The choice of the predominant type of memory used in the TXE 2 and TXE 4 was particularly characteristic of the attitude mentioned in section 5.1: the components to be used had to be of a technology that had been tested over many years.

The choice thus went to the famous "Dimond rings" type of memory, named somewhat hilariously after T.L. Dimond of Bell Laboratories, who invented them in 1945 (see Chapter II-1). These are large-diameter magnetic ferrite toroidal rings using solenoid windings, through which are threaded writing and reading wires.

Widely used as "ring translators" in Western Electric/AT&T's equipment, a similar use in the TXE 2 and TXE 4 systems provided the United Kingdom with a function for directory research in the operation of a not direct-controlled exchange, where the ability to convert a subscriber's directory number into an equipment location identity is essential. Under its British name of "calling number generator (or identifier)", the device performing this function was a considerable innovation in the British exchanges since in Strowger exchanges both equipment and directory numbers had to be the same.

Dimond rings also served as memories for a "class-of-service store" used for providing the class-of-service information assigned to a subscriber line.

6. Specific features of the TXE 2 [8,9]

6.1. Relatively speaking, the TXE 2 was a very simple system; its qualification as one of "robust rustic simplicity" is, moreover, perfectly suited to the sorts of environment for which it is intended.

6.2. Initially, TXE 2 had a nominal capacity of 200–2400 subscriber lines which was later increased to 4800 and even 7000 lines by coupling two TXE 2 units together.

6.3. Its switching network consists of four stages – A, B, C and D – made up of 5×5 or 5×10 matrices. Outgoing calls are routed by way of the A, B., C-switches to outgoing junctors. Incoming calls are routed from incoming junctors via D, C, B, A to the called line. Own exchange calls traverse the network A, B, C – D, C, B, A. Subscribers can be added in multiples of five on the A- switches, thus making the system very flexible in matching the required capacity.

6.4. The central control unit is duplicated, the two units being used for alternate 8 minute periods. The most characteristic feature of its central control unit design is its mode of operation, a processing of all calls on a one-call-at-a-time basis. Call set up has to be accomplished in a very short period of time.

This period, of the order of 50 ms, was one of the parameters which determined the capacity of TXE 2 (including Pentex) exchanges. The control unit had to be free when a register initiated a demand for a sequence of program steps to be executed by it. If the control unit was busy, the register had to wait until it became free. The TXE 2 capacity was determined by the probability of delay likely to be experienced by incoming junction calls in the process of being connected to a register. This delay had to be less than the inter-digital pause when the junction came from a Strowger exchange. [9].

7. Specific features of the TXE 4 [10,11,12]

7.1. While the basic components used in the actual construction of the TXE 2 and TXE 4 were contemporaries and therefore similar, there were substantial differences in the characteristics and architecture of the two systems which, indeed, were intended for quite different uses.

Under GPO planning the TXE 4 was intended in 1973 for large local exchange applications to modernize the United Kingdom telephone network over the next 20 years [13].

The nominal capacity of a TXE 4 exchange ranges from 3000 to 40,000 subscriber lines with the possibility of serving up to 5000 junctions or trunk circuits.

7.2. The TXE 4 was defined as an electronic system based on a sectionalized reed relay switching network and a sectionalized programmed electronic control. It was based on a *modular system structure* offering an evolutionary development potential.

7.3. The *TXE 4 switching network* is of a highly elaborate structure which to some extent marks the zenith of teletraffic research for optimizing a space-division switching network as regards cost, non-blocking conditions and modularity for ensuring easy expandability [14].

The sectionalized switching network is composed of an optional number of separate but identical switching units using reed relay matrices. It is of the single-sided form, all network terminations appearing on one side: the seven stage network (A-B-C-D-C-B-A) is folded back on itself via the middle D stage. The A, B, C stages provide the appropriate degree of concentration or expansion. The D-switches perform a simple inter-unit function.

The main switching network was used for access to registers and other signaling circuits, accesses needed only during short segments of call holding times. The principle used was called "serial trunking".

7.4. *Control of the TXE 4* [15†] is decentralized, involving several (from 3 to 10, or even 20 in the TXE 4A) independent call processors, the "main control units (or MCUs)", that share the traffic load.

A large group of registers (of, say 30–120 registers) is assigned to each MCU. The information concerning subscriber, trunk and miscellaneous equipment is continuously broadcast to all MCUs from a data store. The MCUs employ a program control technique using an unusually compact software: only 5000 program words in the initial TXE 4 versions and, later, 8–32000 program words of 16 bits each in the TXE 4A versions. The use of minimal software in MCUs permits the establishment and supervision of simple calls. Small size exchanges can be initially provided economically ensuring satisfactory growth pattern by the addition of further MCUs (units) on a load sharing basis [16].

Scanning is used by the MCUs to collect information on subscriber lines and trunks. The MCU function is to correlate termination data provided by the scanning process of a data store and information provided by a register. With this information an MCU establishes the requirements for connection and directs call establishment through the switching network by controlling the operation of a marker. The information concerning subscriber equipment numbers and subscribers' class of service, (the "data store"), is provided by cyclic stores which are decentralized to match the modular structure of the switching network. Cyclic stores were devices using Dimond rings.

A supervisory processing unit (SPU) provides control of the exchange supervisory circuits associated with operations such as ringing, call charging and the release of connections.

8. An enhanced version of the TXE 4: The TXE 4A [12,17,18]

8.1. In 1972, as the first orders for the TXE 4 were being placed, consideration was already being given to an enhancement of the system and to a succeeding generation of TXE4s. This en-

hanced TXE 4 was known as the TXE 4A.

STC had been the leader in the design of the TXE 4. It was the prime contractor to GPO and British Telecommunications ("BT") [7] for the production of the system [8] and, quite naturally, it was STC that was officially commissioned by BT in 1975 to develop the TXE 4A. The first objective fixed by BT for the enhanced system was to guarantee a 15% reduction in the costs of an exchange. The second was to provide a system offering new facilities.

8.2. Taking advantage of the modularity existing in the TXE 4 architecture, redesign of the system was confined solely to the control area where integrated circuit technology offered the greatest impact on cost savings.

The organization of the TXE 4 control: cyclic stores, MCUs, SPU, were unaffected. The switching network and peripheral equipment remained unchanged.

TTL and NMOS integrated circuits replaced the bulky "Dimond rings" in the logic and the stores of the TXE 4A. This allowed modifications of exchange data in the cyclic stores to be obtained by keyboard teleprinter command in the TXE 4A, instead of the laborious manual work of threading new jumpers through the Dimond rings.

8.3. A greater processing power due to the increase in memory capacity, reduced amount of wiring and cabling, fewer printed wiring cards, big savings in floor space, some new facilities for both exchange maintenance and services offered to subscribers (e.g. push-button dialling) were among the achievements of the new version of the TXE 4.

8.4. It took five years to develop the TXE 4A and to install the first exchange of this series at Belgrave in Leicestershire, which was cut into service in the Autumn of 1980. In the same year, the first tandem exchange of the new digital British system, the System X (see Chapter IX-5), had been put into service in London and its inauguration rather overshadowed the introduction of the TXE 4A [19b].

By the end of 1988 more than 550 TXE 4A exchanges serving 8 million lines were installed.

8.5. The development of the TXE 4A version offers a typical example of two distinctive features of the switching industry in the 1970s:

– the long delays before mass production of a public exchange model;
– the cost reduction impact of introducing IC components in the system design.

(A part of the delays which occurred in TXE 4A production can be attributed to the competition between two parallel and rival objectives of BT in the 1975–1980 period: the development of its "System X" and the enhancement of the TXE 4).

The impact of introducing new components into the hardware of an exchange, during this period of very fast progress in LSI circuits, has to be correctly assessed by considering that, while a 15% cost reduction objective was finally achieved for a TXE 4A exchange, it corresponds to a cost reduction of nearly 40% for its only part, the control area, affected by the redesign of the system.

7.6. A last remark, anecdotal and of a semantic nature, concerns the inflexion which appeared in the British terminology of the switching language during the 1970s. Unlike that describing the TXE 4 system at the beginning of this period, the literature devoted to the TXE 4A contains references to what may be considered a characteristic feature of its design, namely its "stored program control" nature. Another typical change in terminology is the one noticeable in the replacement of the name "main control units" by "main processor units" in the descriptions of the TXE 4A.

[7] For telecommunications, British Telecommunications replaced the GPO, after the October 1981 Telecommunication Act of the Parliament.

[8] This had allowed STC to increase its participation in the public exchange business with BT from a former level in 1970 of only 20% (its share in the Bulk Agreement, the so-called "Ring System") to a 35% level in 1978 [19a].

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CHAPTER V-7

GERMANY (FRG) = 1960–1979 DEVELOPMENTS

1. Until the second World War, Germany had historically held a leading position in telecommunications for almost a century, first in telegraphy and later in telephony, particularly automatic telephony. Prior to 1940 it had ranked second with the United Kingdom in the telephony field and might have held first place but for the geographical and economic importance of the United States of America.

Owing to the size and automation of its telephone network and the specific originality of its switching systems, Germany was leader in the development of automatic telephony [1].

When the war was over, the organizational structures of its once dominant telecommunications service and dependent equipment industry, to which past successes had been rightly attributed, remained virtually unchanged in the Federal Republic of Germany (FRG) [2]. They were marked by two distinctive features:

- in the case of telecommunications, by the omnipotence of the Deutsche Bundespost (DBP);
- in the case of the equipment industry, by the historically dominance of Siemens.

[1] In the 1930s, Germany was far ahead of all other large countries in the automation of its national network (Volume I of " 100 Years of Telephone Switching", p. 285).

[2] The same was largely true for the organizational structures of the telecommunication Administration in that part of Germany known as the German Democratic Republic (GDR).

2. The Deutsche Bundespost

The DBP comes under the authority of the Ministry of Posts and Telecommunications and as such is an official Administration, its rights and duties having been laid down in an Act of 1953.

The postal (including financial) services provided by the DBP are closely associated with its telecommunication services. While there is one "vertical" directorate for each one of these services at the Headquarters in Bonn, there are three "horizontal" directorates governing personnel, finance and equipment contracts for the entirety of the DBP.

The DBP has a separate budget from that of the State and is required under its constitution to meet the dual objectives of providing service for all subscribers under the same conditions and showing a profit, to which latter end it is placed under self-management (Eigenwirtschaftlichkeit). Its accounts are unified, i.e. there is no clear distinction between postal and telecommunication activities. Deficits in postal services are therefore generally absorbed by surpluses from telecommunication services. The DBP is obliged to hand over a part of its revenue (10% since 1981) to the State.

Enjoying an absolute monopoly over both postal and telecommunication services, the DBP has a turnover which is well above that of any other public or private corporation in the FRG.

3. The German switching industry

Both before and since the Second World War, Siemens has always been in the forefront of the German switching industry and supplies roughly half the equipment ordered by the DBP. It is also the largest German exporter of switching equipment; indeed, exports account for almost half its production, thus making the Munich firm the second largest exporter in the world for that branch of activity.

The other half of the switching equipment ordered by the DBP was supplied at that time by other manufacturers:

- Standard Elektrik Lorenz (SEL) which belonged to the ITT Group [3] and which supplied generally some 30% of the German market
- DETEWE (related to Siemens)
- Telefonbau Normalzeit (of the AEG-Telefunken Group)
- Tekade (part of the Philips Group).

The only equipment produced for the DBP is for those systems it has standardized. Until the mid-1970s, this meant for switching equipment that had ben researched and developed by Siemens. Siemens was therefore by far the largest German spender on research and development. Once a system of Siemens design had been standardized according to the DBP requirements, licensing agreements were given to other German manufacturers for production under DBP contracts [3] and a guaranteed share of the DBP orders was assigned to Siemens.

This German model of a switching industry is an historic one whose roots can be traced back to the beginning of this century. It reflects a constant and extremely rigid policy on the part of the German telecommunications Administration which wanted only one system installed in every exchange in the country:" One country, one administration, one system ...".

The standardization by the DBP of Siemens' EMD in 1953, at a time when Germany was going all out to reconstruct its war-battered telephone network, ensured the network itself of remarkable consistency and guaranteed the success of the EMD system: almost 60 million EMD lines [4] were installed both in Germany and in many other countries. For some 20 years to come, i.e until the mid-1970s, the competing crossbar and EMD uniselector systems represented the last two major types of electromechanical systems.

4. Research for a new switching system

4.1. Every success eventually reveals drawbacks if it does not actually produce setbacks. Nowadays, inflexible structures are inevitably outflanked by technological developments. Admittedly, the choice of a single standard system offers considerable economic advantages and definitely facilitates the administrative procedures of a telecommunication enterprise. However, maintaining that choice over a very long period is bound to raise many problems affecting:

- the improvements obtainable by more modern switching techniques,
- the diversity of the services offered by the telecommunications enterprise, and
- the international competitivity of the equipment the manufacturers export.

4.2. The risks of such a situation were duly perceived by those in charge of Germany's telecommunication research departments who, by the late 1950s, expressed concern about the possible impact of electronics on telephone switching.

[3] The ITT yearly reports included statistics on automatic lines produced by the various companies of this multinational group. The lines were categorized according to each type of switching systems. During many years, the largest number of lines in a specific system was corresponding to the item "rotary" (with a small r. and not the capital R, initial of the "Rotary" ITT trademark). These "rotary" lines were the EMD lines produced by SEL for the orders of the DBP.

[4] See Volume I "100 Years of Telephone Switching", pp. 240 and 245 wherein 40 million lines are quoted for production until 1981, meanwhile in 1987 this figure has increased to almost 60 million lines.

Fig. 1. H. Panzerbieter

In 1958, an article by H. Panzerbieter (Fig. 1) of Siemens' Zentral Laboratorium [1], which appeared in the DBP's annual compendium of fundamental articles known as the *Jahrbuch des Elektrischen Fernmeldewens*, gave a masterly account of the different options open:

- the switching network: choice of time or space-division switching and rejection of frequency multiplexing;
- the abandonment of step-by-step selection and the introduction of registers together with switching networks operating (at least partially) according to the conjugate selection principle (the "link system" [5]);
- the need for markers to serve as intermediates for reconciling the different operating speeds of switching network components with that of electronic control units.

4.3. H. Panzerbieter offered not only working hypothesis in his article. He also mentioned several prototypes that were already in the study or design stage at Siemens' laboratories. These fell broadly into two categories known as ESK and ESM after their German initials for the characteristic components of their switching networks:

- ESK: High-speed relay with noble metal contacts
- ESM: Electronically controlled system with magnetic field switching matrices and dry reed contacts.

5. Systems of the ESK family

5.1. The ESK relay featured in these systems had been designed and developed at Siemens' Munich laboratories in the mid-1950s (the first information published about ESK appeared in 1957 [2,3] [5]. The ESK relay might be said to mark the apogee of electromechanical switching research in the quest for ever faster [6] and more reliable relays. Designed initially for PABXs and marking the development of a fast relay that had already been used in the first mock-up of the KAMA electronic exchange (see Table 1 in section 8.1 below), the ESK relays were soon regarded as having all the necessary virtues for installation in public exchanges [7], both as switching network components and for use in the network control units.

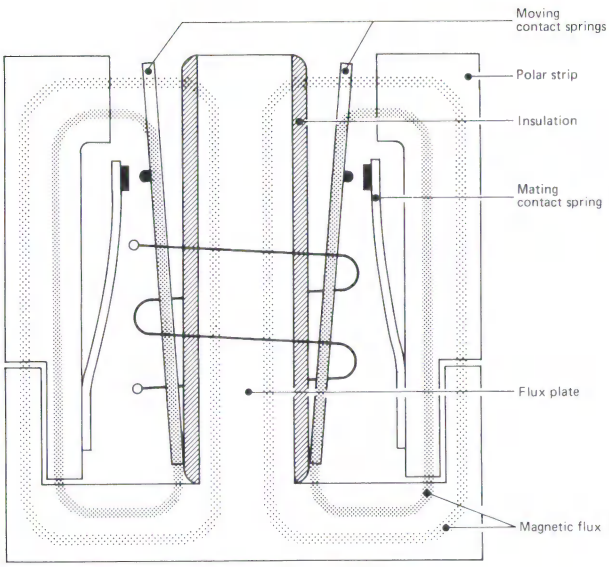
5.2. The ESK relay

A description of the ESK and its mode of operation is given in many publications, particu-

[5] At this time, Siemens was simultaneously exploring two lines of development for components that could be used in switching matrices, for electronically controlled switching systems, namely miniature crossbars and modules consisting of strips joining five ESK relays.

[6] The operating time varied according to the conditions in which the ESK relay was required to function but its characteristic magnitude was of 2 milliseconds.

[7] Telephone but also telex exchanges designated by the initials TWK



Basic design and operating principle of the ESK relay with its superposed magnetic flux paths

Fig. 2. Schematic showing mode of operation of the ESK relay with flux superposition in the operating air gap (from reference [4])

larly [4]. Despite the simplicity of Fig. 2 depicting the geometry of the relay's mechanical construction, anyone wishing to understand the subtleties of its design might usefully refer to publication [4] which, with colours printing not available in the present book, differentiates and highlights:

- the arrangment of the ferrite middle core and polar strips of the magnetic circuit;
- the position of the exciting coil wound round the middle core,
- the arrangement of the magnetic contact springs fitted with twin silver palladium contacts;
- and, above all, the paths of the magnetic flux controlling the operation of the contacts without any bouncing of the contact springs.

Experts interested in the ESK system will also find in the same publication a description of the assembly linking five ESK relays mounted on strips with a continuous contact bank, thus constituting the standard component for the construction of switching network matrices.

The manufacture of ESK relays was highly automated allowing a mass production of these key switching components at a highly competitive cost. The number of such relays used in Siemens equipment in 1968 was estimated at over 50 million.

5.3. PABXs of the ESK family

The ESK relay had originally been studied for building PABXs with a small number of lines. However, the range of ESK PABX capacities offered on the market steadily grew over the years, particularly from the early 1960s when it jumped from 400 to 3000 lines. The equipment was a great success and sold throughout the world: by 1982 it was estimated that more than 6 million of extension lines were being served by such PABXs.

5.4. The ESK 10,000 E system for public exchanges [5]

5.4.1. More than the PABXs covered by this book in a purely secondary fashion, it is on the ESK family of public exchanges, marketed mainly as the ESK 10,000 E type, that we should now concentrate. Their family represents the transition for Siemens between electromechanical and electronic switching. Their architecture also marks a development [8] that is highly characteristic of the evolution of the German switching techniques, i.e the abandoning of Germany's tradition of establishing the connection step-by-step through successive selection stages corresponding to each digit of the called number. The architecture of an ESK exchange was aligned on the conventional architecture used in most other systems, particularly those of the widespread crossbar families. It consisted of:

- a speech path network (the switching network).
- a centralized equipment network, i.e a central control.

[8] This development had long been advocated by Siemens engineers, e.g. Panzerbieter in 1958 (see 4.2 above). To a lesser extent it had also emerged in later versions of the EMD system incorporating registers (see Volume I, p. 239). The letter "E" in the system's designation ESK 10,000 E stands for "Electronically controlled".

5.4.2. The family of Siemens ESK 10,000 E crosspoint systems encompassed exchanges of any size, from small rural exchanges with only a few subscribers to large local ones which could serve as many as 100,000 subscribers. This family also included systems for automatic 4-wire transit exchanges handling national and international traffic and ranging from small capacities up to nearly 50,000 trunk lines.

5.4.3. Basic trunking schemes of the ESK switching network

For local exchanges, the ESK switching network is divided into two blocks:

– the subscriber switching network "TW" (a "line selection unit") for traffic concentration and expansion, with a 4-stage (ABCD) trunking scheme. One trunking unit of the TW block serves 1000 subscriber lines.
– the route switching network "RW", equivalent to a "group selection unit", for traffic distribution, with either a 2-stage or a 4-stage trunking scheme according to the exchange capacity.

The 4-wire switching network in transit exchanges follows the same building-block principles as the ones used for the RW stages in the local exchanges. The basic 4-stage trunking unit has 600 inputs and outputs.

The various stages of a switching network unit consist of crosspoint matrices, each being the association of two parallel matrices with the same coordinate system (Fig. 3).

– the selection matrix of semi-conductors, preceding
– the contact (or switching) matrix of ESK relays.

Each trunking unit of an ESK switching network is controlled by a marker according to the conjugate link selection process.

5.4.4. The central control

Different types of central control are used in the ESK family of public exchanges, depending

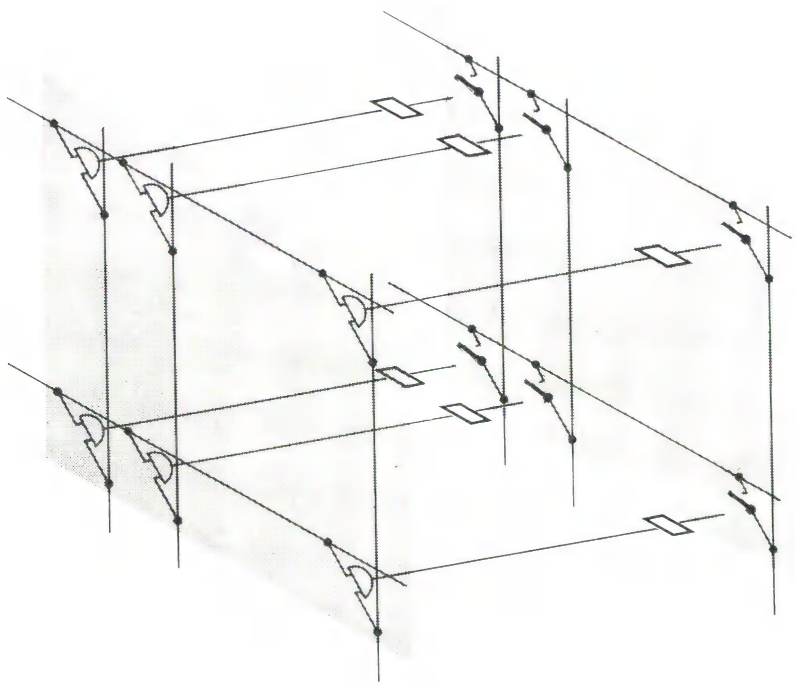


Fig. 3. Elementary dual-function switching processes connect the selection matrix (left) to the contact matrix (right) in the switching network of ESK crosspoint systems (from reference [6])

on the nature of the exchange (local or transit) and, in the case of local exchanges, on their subscriber line capacity. Centralized control units therefore range:

a) from those used for small capacity local exchanges having only a two-stage RW group selection block, in which case they consist solely of a central marker and a digit translator;
b) to those used in very large local exchanges and transit exchanges, in which case an SPC-type centralized control is exercised by an electronic control "801" unit.

In case a) above, except for the translator with its ferrite-core read only memory (ROM) and semi-conductor hardware logic, an almost purely electromechanical form of switching is used. Case b), on the other hand, may be classified as beginning to belong to the family of SPC space-division exchanges. Both these observations justify the opinion offered when we began to describe ESK systems (see 5.4.1 above), namely that they represent a prototype of transition from electromechanical to electronic technology.

5.5. Relative successes of the ESK 10,000 E system

Was that the reason why? Or was it because another system, the EWS, was already in sight (see section 10 below)? Or, again, was it because the DBP was perfectly happy with its standard "V55" (1955) system, i.e the EMD system, the very foundation of its highly decentralized network with its numerous small capacity exchanges for which the cost of a centralized control with registers and digit tranlators would have been unjustified? Whatever the answer, the ESK 10,000 E system was not adopted as a standard by the DBP which did not install a single ESK local exchange in its network.

However, and perhaps as a consolation prize, the DBP introduced the ESK 10,000 E system to a large extent for handling the international telephone traffic. The international trunk exchanges at Hamburg, Hannover and Berlin were fitted in 1966 with a ESK system, called "Technik 66" and other 13 smaller trunk exchanges lying immediately at the country borders were equipped with ESK-"Technik 64", a smaller variant of the ESK-family. Later, the biggest German international trunk exchanges at Frankfurt, Dusseldorf and Munich were equipped with the "Technik 70" which corresponds to the ESK 10,000 E system with electronic control "801" as delivered abroad. The international exchange at Frankfurt had the greatest installation of the ESK system with 48,000 trunk lines (24,000 incoming and 24,000 outgoing). A complete description of all techniques used in the DBP for international trunk exchanges is given by Rosenbrock in [7].

In addition to these international exchange installations, the DBP used ESK-relays in the national trunk exchanges as components for coupling the registers to the group selection stages to be operated ("Technik 62").

The ESK 10,000 E system therefore had mainly to seek its fortune outside Germany, whether exported from Germany or manufactured abroad by foreign subsidiaries of Siemens or related companies, particularly in Austria, Italy and Switzerland.

The first ESK exchanges were installed in 1966, not only at Düsseldorf but also at Absdorf, in Vienna (Austria). The next went to Hong Kong, followed by Austria again, then to Denmark, Finland, Indonesia, Italy (transit centres in Florence, Milan-International and Turin), Switzerland and several other countries. Although sometimes known otherwise than as ESK 10,000 E, all the ESK public exchanges installed in some 20 countries were together serving over 6 million lines by early 1982.

The ESK Swiss systems produced by Albiswerk were designated ESKA (A-Albiswerk). A non-SPC version of the system was sold under the designation ESWCP24 (CP = crosspoint) in the United States, South Africe and Nigeria. An SPC version was known as EWSCP44 (Crosspoint 44).

6. Research by Siemens into electronic switching

The development of the ESK family provided a gradual change in Germany away from electromechanical step-by-step EMD systems and to-

wards the introduction of indirect control systems incorporating registers, markers and a switching network under centralized control. Siemens was pursuing – again in line with the ideas expressed by Pfleiderer in 1958 – a whole series of studies into two forms of electronic switching, namely time-division and space-division switching.

7. Time-division switching trials in 1962

These Siemens trials have been described in Chapter II-5 under section 3 (3.1, and more specifically 3.3) where they are covered in parallel with other contemporary trials of time-division switching systems.

Table 1
The pre-EWS Siemens prototype models (1958–1968)

Period	Name	Switching Network	Control	Elements
1958 (Kama studies from 1952)	KAMA (mock-up model)	Early ESK relays	Indirect	Hot/cold gaz tubes
1959	ESM I (PABX in Siemens)	Decimal trunking Large reed relays	Direct. Wired logic	Relays and semi-conductors, transistors
Nov. 1962	ESM II München Farber-graben (500 and later 3000 lines)	Decimal trunking. Dry reed relays in 10 × 20 arrays (intra = 7 stages inter = 7, 9 or 11 stages)	Wired program	
June 1965	ESM III Rome (Italy)	Link selection. ESK relays. Non decimal trunking. 10 stages (intra or inter)	Indirect and centralised (a system architecture similar to the KAMA system, but with conversion to transistors.)	Wired semi-conductor logic. (One electronic marker only, duplicated for 10,000 lines.)
1968	System IV (mock-up model)	Steel-enclosed reed relays ESM (in 8 × 8 arrays). Network (up to 14 stages) with map in memory	SPC + multi-processors	Integrated circuits * Memory: Ferrite cores (with magnetic tape back-up)

8. Successive stages of research by Siemens into space-division switching [8]

8.1. These researches took place between 1958 and 1968. They were conducted in parallel with the studies on the ESK family. Table 1 briefly indicates the chief characteristics of the five successive models produced. It was from those models that, after a slow process of gestation, the EWS (Elektronischen WählSystem) was submitted to the DBP in the mid-1970s for standardization. Although a typical example of the first-generation (space-division) of SPC systems, EWS had only a short life before it was replaced by a younger brother from the Siemens' stable, namely the EWSD (D for digital) system of the second generation, i.e. digitally switched SPC systems.

We shall come back to the EWS and EWSD systems later, but first let us briefly analyse the major design options taken up for the five prototype models mentioned in Table 1.

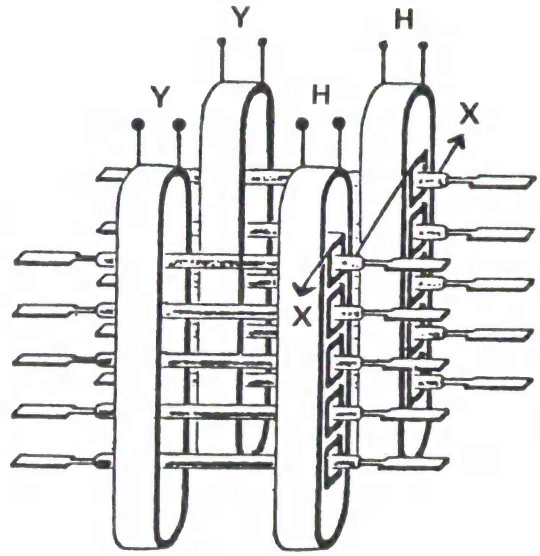


Fig. 4. Control wires (X and Y) and the holding wire (H) arranged round the rectangular coordinates of the matrix of the switching network relays.

8.2. The design of the switching networks of these five prototype models:

a) opted without hesitation for the space-division switching method: a switching network consisting of metal contacts was then considered to be the only solution compatible with the transmission quality constraints expected of a public exchange;
b) introduced as basic components of the switching network crosspoints in the form of rectangular matrices (as in crossbar systems);
c) introduced the principle of link selection between the sets of matrices which made up the stages of the switching network;
d) conducted intensive research into a whole range of possible solutions to find the basic switching network component which would offer the highest performance as regards speed of operation, quality of contacts, reliability, life and cost. Two options were eventually short-listed:
   – magnetic spring relays, the development of which had led to the production of ESK relays,
   – reed relays, initially in a gas-filled glass capsule and later metal-enclosed in an envelope made of magnetically-conductive material;
e) gave preference to grouped magnetic control of the relays in a common matrix unit. This was effected by means of coils having their control wires (X and Y) and their holding wire (H) arranged round the rectangular coordinates of the matrix to select the point of contact. It was this arrangement, shown in Fig. 4, which gave rise to the initials ESM (Elektronisch System mit Magnetfeldkoppler) which designated three of the systems indicated in Table 1.

8.3. It will be noted in connection with the control organs of the systems shown in Table 1 that:

a) the successive choices of electronic components used in the different models reflect the fast technological evolution of these components;
b) depending on the type and of the control used in each prototype and on their speed operation, there was an ever increasing concentra-

tion of the control functions assumed, until System III had only one organ – the central marker – for operation throughout the switching network;

c) the control organs retained wired logic linking relays and semi-conductors. A SPC-type of design appeared only in 1965 with System IV which had a central organ of the processor type incorporating a ferrite core memory.

8.4. With the exception of System IV, the architecture of the systems in Table 1 was somewhat traditional because their design was limited by the constraints of having to fit into the DBP's network with its direct step-by-step control system. Moreover, all the systems were simply prototype local exchanges, so the architecture of System ESM I-II may be regarded as a mere technological transposition of a step-by-step system. (System ESM III was the first to use register control).

8.5. The inauguration of the Munich-Färbergraben ESM II local exchange on 9 November 1962 was regarded as an outstanding event at the time and was celebrated in Germany as marking the first "electronic type" of exchange ever opened for public service [9,10]. It served 3000 subscribers and remained in service for a surprising number of years. Incidentally, its introduction coincided almost to the day with the entry into service of Britain's time-division switching exchange at Highgate Wood, the inauguration of which was celebrated in the United Kingdom in the same triumphant manner.

9. Prototypes researched by other German manufacturers

9.1. While Siemens was engaged in research on space-division prototypes, Standard Elektrik Lorenz (SEL) and Telefonbau und Normalzeit (TN) were also working on two prototype systems.

9.2. The SEL design was called the HE 60 [11] and was a contemporary of Siemens' ESM II. A 2000-line local exchange model was put into service at Stuttgart (Blumenstrasse) in 1963, followed by two other HE 60 systems, still in operation in 1986, installed in 1964 by the DBP to serve the international transit exchanges at Stuttgart and Nürnberg. Another HE 60 trunk exchange was installed in 1966 at Vienna by the Austrian Administration.

The HE 60 was designed as an indirectly controlled system with registers and a link-selection-type switching network. It was thus a clear departure from the step-by-step systems with selection at each stage to match the digit dialed, as was the case with the contemporary Siemens exchange at Munich-Färbergraben. The HE 60's 10-stage switching network consisted of matrices of reed-relays, encased in a sealed glass tube and linked five per strip.

9.3. TN's FRK system was of similar design [12]. It too used indirect control, magnetic-core registers and reed-relays matrices in its switching network. A 1000-line local exchange of this type was put into service experimentally at Eckenheim in 1965.

10. The EWS system [13]

10.1. From the mid-1960s onwards, the success in the United States of the ESS 1 system, the world's first SPC system ever introduced in large numbers, inevitably persuaded the DBP of the value of the research on electronic switching which until then the German manufacturers had been conducting on an individual basis with the DBP's encouragement.

Despite the considerable upheaval which the new SPC design was bound to cause in the highly organized and rigid structure of its own step-by-step oriented network, the DBP after some hesitation decided in the late 1960s to reach agreement with all the German manufacturers on what was to become its future standard system, namely the space-division switching EWS system (Elektronisch Wahlsystem). Under the terms of this agreement, the EWS was to be developed jointly by those German manufacturers who had

been associated with Siemens for that purpose under the control by the DBP's research departement (FTZ) at Darmstadt.

Obviously, Siemens was to play a major role in the research process, not only because its System IV – mentioned in Table 1 – had since 1968 formed the foundations of the future EWS system, but also because it had more specialized staff in its switching division at Munich.

10.2. Much has been written about the EWS system. The many articles and papers still existant fall into two quite different categories reflecting the time at which they appeared and the standpoint of their authors:

- first there were the engineers who wrote articles describing the purely technical merits of the system until 1979 when the DBP decided to stop installing EWS exchanges and opted instead for a digital switching system which it was to standardize by the mid-1980s.
- later there were the sociologists specializing in industrial economics who in the 1980s made a critical analysis of the management structures prevailing in the FRG's telecommunication sector.

It was naturally the first group which caught the attention of those with a technical interest and to which we are essentially referring here. Although less abundant and less known, the analytical literature produced by the second group should not be overlooked by any reader exercising responsibility at the highest national level; indeed, it teaches an important lesson which we find reflected in many other examples given elsewhere in this book, namely that as much as or more than engineering skill, it is the national structures governing relations between the operation of public telecommunication services and the switching equipment industry which determine the success of a switching system.

10.3. To return to subjects more academic and less open to political controversy, let us briefly describe the architecture of the EWS system, its specificity and its applications.

10.3.1. The system was from the beginning an ambitious project designed to ensure the complete renewal and modernization of the German telephone service in the interests both of subscribers and of the DBP itself:

- to subscribers it meant access to a whole range of new services which in many countries had become conventional by the 1970s, including e.g. abbreviated and push-button dialing;
- to the DBP it signified optimum operating conditions (subscriber-controlled features, unattended switching centers, Remote Switching Units (RSUs), centralized operation and maintenance, etc.) and, for exchanges, specific system structures such as modularity, space-saving design, short installation time, easy maintenance, high reliability, long service, etc.

There were two versions of the EWS system:

- one for local exchanges – the EWS O – in which the remote control switching units were possible;
- one for trunk exchanges – the EWS F – with 4-wire switching.

A third version, the digitally-switched EWS D, was contemplated from the outset. In the early 1980s is was having to compete with other systems for standardization as the DBP's future system. We shall come back to this in Chapter IX-6.

10.3.2. The architecture of the EWS system is broadly but very clearly described in an article by H. Kunze [14] of the DBP, published in 1973 and reproduced in the 1977 IEEE compendium ([3] of Chapter V-2). The EWS architecture consisted in three levels:

(1) that of the central (duplicated) processor,
(2) an intermediate control equipment level for controlling the level (3) components;
(3) the switching network and all the so-called peripherals, i.e. the organs attached to subscriber lines (in the case of the EWS O) or to trunk and service circuits.

A duplicated bus system connected the two sets of levels: levels (1) and (2), levels (2) and (3).

10.3.3. The EWS *switching network* structure is designed as a reverse (folded) trunking scheme:

subscriber lines (in the EWS O), junction circuits, trunk circuits and the register inputs and outputs are thus connected to one and the same side of the network [9].

The switching network carries only the speech wires: two wires for a local EWS O exchange and four for a trunk EWS F exchange. The idle/busy conditions of access to the switching network are mapped in the central processor memory, whose software determines the path to be used within the switching network.

The switching network consists of matrices (generally of an 8×16 type) of a miniature metal-sealed gas-protected relays developed by Siemens and used in the construction of the System IV prototype (see section 8 above), the predecessor of the EWS [10]. These unique relays for crosspoint contacts were very small and manufactured completely by automation [15].

10.3.4. As in the System IV, the EWS *central processors* were duplicated. Both processing units operate in the micro-synchronous (parallel operation) mode and are supervised by means of comparator circuits. The main memories are also duplicated.

Whereas the memories in the processors of the first experimental EWS exchanges (see section 10.4) were ferrite cores, they were replaced in the mass-produced versions of the EWS by MOS semi-conductor memories, having a capacity of 2 or 8 M octets depending on the type of processor (SPP 102 or SSP 103) which corresponded to the exchange capacity, i.e 50 K or 200 K BHCA. The processor instructions used a 32-bit word structure, with each word containing an additional 7 error control bits.

Table 2
EWS software Dimensions (reference [16])

Executive programs	50,000 instructions
Switching programs	40,000 instructions
Safeguard programs	250,000 instructions
Utility programs	100,000 instructions

Table 2 indicates what was then the considerable dimension of the EWS software, broken down according to the nature of the functions performed.

Software controlled the processing of signals in the peripheral circuits groups. It was stored under a 56-Koctet memory, separately for each device in the controls of the peripheral circuit group.

10.3.5. Most of the EWS operation and maintenance functions were centralized and performed by a service computer which had to serve about a dozen EWS exchanges and thus a set of some 300,000 subscriber lines. The computer itself was a conventional general purpose computer in the Siemens 7000 series. Its two main tasks were:
- to act as a computing and storage aid for the EWS system,
- to handle the maintenance, fault clearance and customer services tasks.

10.4. The introduction of the EWS system started in 1974 with three model EWS exchanges produced by the various German manufacturers participating to the EWS project – one each at Münich-Perlach, Stuttgart-Feuerbach and Darmstadt – for detailed and extensive trials under real service conditions. Following this, the first EWS local exchange of the mass-produced type, serving 7000 subscriber lines, was put into service in october 1977 at Münich-Rablstrasse. In 1976, the DBP placed in service at Neuss its first service computer as an essential preliminary to the duly planned introduction of a whole set of EWS exchanges following the one at Münich-Rablstrasse.

[9] For local (EWS 0) exchanges this switching network replaced the traditional architecture consisting of: (i) a subscriber stage with the functions of concentration/expansion, and (ii) the usual "group selection" stage.

[10] These metal-sealed relays were to be even more widely used as basic components in the manufacture of the EMS family of Siemens PABXs. The EMS exchanges operate under the control of a microprocessor – hence their English acronym (Electronic Microprocessor Stored) – which, incidentally, corresponds to the German initials used for the relays themselves. They have a served line capacity ranging from the medium sized ("EMS 30") to up to 12,000 extension lines ("EMS 12,000"). Widely installed throughout Germany (FRG) and in many other countries, they were serving over 1.5 million lines by 1983.

10.5. The DBP had been carefully planning the introduction of EWS exchanges for a number of years and had taken into account their characteristics which were very different from those of the German step-by-step type (HW or EMD) electromechanical exchanges they were gradually to replace.

First, this reflected the far greater size of the EWS models:

Those of the EWS O local type were built to serve 25,000–75,000 subscriber lines. An EWS O exchange could accept up to 32 remote switching units, each of which could therefore serve as a virtually autonomous but small capacity satellite exchange. Then again, the EWS O exchanges operated very differently from electromechanical exchanges for handling trunk traffic or, within a multi-exchange area, junction traffic between exchanges: in particular, they offered possibilities, until then unknown in German local exchanges, for alternate automatic routing and for a two-way mode of operation of each trunk group.

The EWS F trunk exchanges were also designed to be very large and their intended capacity was to serve up to 13,000 trunk circuits.

Two special features of the DBP's EWS planning programme reflected the step-by-step structure of the German network:

- the large number of RSUs which an EWS exchange could serve so that many of the small exchanges in the German network could be replaced by RSUs which, incidentally, could also be collocated with step-by-step exchanges to expand their overloaded capacity.
- The fact that, to hasten the establishment of independent EWS local networks, the DBP had to assign a special code (the first digit in the directory number) to the subscribers of an EWS exchange.

10.6. Manufactured from 1977 onwards by all the German manufacturers (SEL, DETEWE, TN and, of course, Siemens) to meet orders from the DBP, by 1981 the EWS system served over a million lines installed in almost 100 exchanges, most of these lines (500,000) for the DBP, but also (Siemens export) in Argentina, Egypt, Luxembourg and the Philippines.

11. In 1979 an abrupt change in the DBP policy for the choice of its future switching system

11.1. There was a sensational turn-about in 1979 when the DBP renounced the space-division switched EWS system.

11.2. The standard system the DBP wanted had for two reasons to be introduced over a very long period of time:

- first, the DBP's dynamic policy had led to so vast a penetration by the telephone in the FRG that only a very moderate expansion of the subscriber line base providing just the plain old telephone service could be envisaged;
- second, the exchanges installed were relatively modern because the entire German network had been reconstructed from, say, 1955 onwards and had since expanded considerably, particularly from the 1970s.

11.3. Thus, in 1979, the DBP wanted to standardize a time-division digital-switching system for a very long time to come. It was a policy choice consistent with the one which was beginning to obtain a general consensus in the telephone switching world [11].

Digitization of the German network had gained much ground in the late 1970s. The international standardization of the 32-channel/2048 kbits/s PCM primary multiplex led the DBP to install a great many of them. Their presence placed digital exchanges in the forefront of the DBP concerns. An attempt to graft time-division switching parts within the space-division structures of the EWS to take PCM circuit terminals [17] had little impact.

11.4. Many other reasons could or might be involved to explain the DBP's disavowal of the EWS system:

- the accelerated development of microelectronics: the introduction of LSI components and,

[11] 1979, the year of the Paris ISS, (or let us say 1980 which is easier to remember), may be taken as the year(s) of a swing by general consensus in favour of digital switching.

more important still, of micro-processors which it proved extremely difficult to graft onto the existing EWS hardware structures;
- the growing interest in and importance attached to the ISDN in the late 1970s. This concept was doubly favoured in the FRG owing to the DBP's absolute monopoly over all telecommunication services and to the fast development of German research on data packet switching, teletex and videotex.

11.5. The digital switching system which the DBP decided in 1979 to standardize for the mid-1980s would not necessarily be the EWS D system that was then in the offing. It proposed to adopt whichever system(s) won an open competition among German manufacturers. The industrial cooperation which the DBP had introduced to enable German manufacturers and its own technical services to study the EWS system in common went by the board. Its own research facilities were in the future to confine themselves to judging and assessing systems that were in stiffer and parallel competition.

11.6. In military circles, strategists at the offices of the chiefs of staff and in the military academies are constantly playing war games to determine what made this side win and that one lose. They peep through a microscope, as it were, at how the command was organized and whether the responsibilities assigned to the different partners in the command were consistent. In addition, they analyse the terrain and the environment, logistics, the means assigned to the combatants and so on ad infinitum.

In both economic and financial industrial sociology, management schools and institutions are now starting to indulge in the same sort of exercise, although the case studies given to students to consider are usually fairly simple or even very simple models. There are thus few in-depth studies made for analysing large-scale industrial phenomena.

In the case of the EWS system the sudden halting of a project which had been researched over more than ten years at a cost of hundreds of millions of dollars was seen by some management analysts as an exemplary model. Going beyond the journalistic criticism which Germany's more serious press had been discreetly levelling at both sides in the argument, there emerged in the early 1980s a number of publications devoted to what was the first serious change in over half a century in the historic relationship between the German Administration and Siemens, its privileged supplier.

Some of these publications emphasized the merits of vertical integration between telecommunication operating services and the equipment manufacturing industry or of a closer symbiosis between both partners, while others questioned the relations between the ministerial departments responsible for ordering equipment and their own research departments, ones in which conflicts of authority were bound to arise. Instead or going into detail here on such a potentially polemical subject, let us simply refer to a few of the little-known publications and articles, those in [18–23], which, at a time when deregulation and the optimum structures of telecommunication bodies are a favourite topic of conversation, might well provide the top designers of national policy with food for thought.

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CHAPTER V-8

FRANCE – FROM ARISTOTE TO E10

1. Bodies concerned with switching research in France

1.1. In France, the beginning of electronic switching studies can be dated to 1957, with the establishment of an Electronic Machine Research Department (RME) by CNET, the PTT Administration's study and research body [1]. It will be noted that the start of French studies in this field coincided with the time when information began to circulate about key decisions by Bell Laboratories to develop an SPC type system.

1.2. Until then switching research in France had been solely the purview of equipment manufacturers. The design of the many types of systems used in the French network was the work of three manufacturers, which were subsidiaries of foreign international groups:

- two of them, "Le Matériel Téléphonique" (LMT) and the "Compagnie Générale de Constructions Téléphoniques (CGCT), belonged to the ITT group, the first concentrating on producing exchanges for large towns and very large cities and the second equipping smaller ones;
- the third, the "Société (française) des Téléphones Ericsson" (STE), was, as its name shows, a subsidiary of the Swedish group LM Ericsson.

These three manufacturers shared the French public market with a fourth, "CIT (Compagnie Industrielle des Téléphones) – (later) CIT – Alcatel", which also produced switching equipment, but usually under license from its partners because of agreements imposed by the Administration in order to standardize its systems.

The four companies naturally had their own research departments. At least in the case of the first three, those departments depended essentially on the parent company in which they worked in close cooperation with its other industrial establishments outside France, such as BTM in Belgium in the case of the companies in the ITT group, and the research laboratories of Midsommarkransen in Stockholm in the case of STE.

1.3. The idea behind the establishment of CNET in 1944 was that it should become, in close association with the telecommunication operating services, a research body modelled after Bell Laboratories in the United States and Dollis Hill in the United Kingdom [2].

During the first ten years of its existence, from 1944 up to the mid-1950s, CNET came under the Directorate General of Telecommunications (DGT) of the Ministry of PTT. Most of the research assignments were consequently aimed at solving the most outstanding problems in the French network severely damaged by the war. Priority was given to the trunk service, to restoration of its network of long-distance routes, and to its expansion. In telephony, therefore, CNET's research was essentially applied in the field of transmisstion: studies on radio relay links and on multiplexing, particularly digital multiplexing. Switching on the other hand remained for CNET

a field of activity which was reduced to a very minor role: mainly studies leading to the development of electromechanical systems with very low capacity for rural automatic exchanges. This proved very useful in serving rural communities in a sector which had been somewhat disregarded by industrial manufacturers, presumably because of the very limited market it offered at this time in their French limited sphere of action.

1.4. The few engineers assigned from 1950 onwards to the CNET switching Department had scarcely any facilities. They were therefore reduced to pondering on the different functions that a telephone exchange should perform and keeping up to date with what was being done abroad. This period during which they let their ideas mature was to prove extremely fruitful in the influence it had later. They also plunged into the study of new principles for the development of electrical circuit logics, which had emerged both in the computer industry and in telecommunication research departments. This period in fact saw the birth of a whole body of scientific doctrine which, based on the work of C. Shannon and the principles of Boolean algebra, proved to be very useful design practices for switching equipment and computer technology [1)].

1.5. From 1954 onwards and under the authority of a dynamic director, P. Marzin, CNET gained a wide degree of autonomy [2]. The period 1958–1968 coincides with the time when the RME Department began to develop its activities and represents a second and new phase in the development of CNET, which from then on concentrated more on fundamental research. It was a period of vigorous expansion for CNET. Its research budgets increased substantially and so did its staff: side by side with the Administration's engineers there were now people doing research on contract. They came from scientific and technical backgrounds far removed from those with which the Administration was traditionally concerned.

A French policy of decentralization led to the emigration of part of the CNET staff from the headquarters at Issy-les-Moulineaux (a suburb of Paris) to the green fields of Brittany. They settled down in the resort area of the Channel coast in the little town of Lannion [2,3)], which was to play an important role in electronic switching studies. Under the auspices of CIT-Alcatel, the "Société Lannionaise d'Electronique (SLE)" set up there at the end of the 1960s saw to the industrial application of the CNET research workers' ideas. This was the seed from which the world's first exchanges with time-division digital switching were born in the 1970s (French system E.10).

1.6. To finish this brief account of the institutions on which switching studies in France were based, we may also mention the establishment in 1958 of a body known as SOCOTEL, whose members were the Administration and its main suppliers of switching equipment. Along the lines of what had already been done in the transmis-

[1)] In telecommunications teaching (provided in France by the "Ecole Nationale Supérieure des Télécommunications (ENST)"), all these new principles were inculcated into new generations of engineers by Blanchard, following up the work done at Bell Laboratories by Keister, Ritchie and Washburn and the earlier work done by Nakasima and Hansawa in Japan.

[2)] Lannion is the town near which Pleumeur-Bodou is located. Pleumeur-Bodou is the location of France's first earth station, which has been in service since 1962. It also happens to have been the birthplace of the Director of CNET, a Breton. We have seen (Chapter IV-3, section 3) that the electronics boom in California and the birth of Silicon Valley were initially sparked off by the fact that W. Shockley was a native of Palo Alto. Same causes, same effects...

The establishment of CNET (CNET-II) at Lannion had the effect among other things of making northern Brittany one of the most thriving regions in France for the telephone equipment industry and for electronics.

[3)] The migration of telecommunication research centres out into the country, away from the big cities, is a phenomenon characteristic of this time. Confining ourselves to examples relating specifically to switching, we may cite the establishment of the Holmdel Center in New Jersey and the Indian Hill Center near Chicago by Bell Laboratories. Many other examples have already been mentioned in Volume I (see p. 36 of that Volume).

sion field (SOTELEC), SOCOTEL's task was to coordinate the work of the manufacturers' research laboratories with that of CNET. A patent pool was set up among SOCOTEL partners. SOCOTEL also issued a journal entitled "Commutation et Electronique", the first of its kind, which rapidly became famous and achieved a wide circulation in its highly specialized field.

2. First phase (1958–1964): exploratory and experimental research [3]

2.1. SOCOTEL divided up the research work among its members: i) the CNET laboratories had to work on "full electronic" exchanges; ii) research departments of the manufacturers, on space-division switching systems.

The CNET laboratories on switching were those of the RME Department (see Section 1.1) set up in 1957. This RME Department represented a pool of skilled "switchers", and of "transmitters" who were experts in electronics technology. The new RME Department was placed under the authority of one of the "transmitters", Louis-Joseph Libois (Fig. 1). He came from the Transmission Department where he had directed studies on digital multiplex and had distinguished himself by brilliant work on delta modulation.

Fig. 1. (from the left to right): André Pinet and Louis-Joseph Libois, the "founding fathers" of the E10 system

2.2. The RME Department's first studies were devoted to exploratory development on both:

- the architecture of electronic exchanges; and
- their basic unit devices, i.e. memories, logical circuits, types of the cross-point matrices to be used in the switching network [3].

Two entirely different electronic switching prototypes were developed for this purpose at CNET. They were both given the names of Greek philosophers: Aristotle for the first and Socrates for the second. These names were in fact acronyms framed from the initial letters of the words in a complicated title, which was supposed to indicate what each prototype was to be. In reality, the long sequence of words in the official title, which was forgotten as soon as it was made up, was essentially a piece of word-play thought up by clever minds with a bent for philosophizing. (The final "E" of the French names of these two philosophers was, of course, the initial of the word "Electronique".)

2.3. Aristotle [4] was a model to be used in setting up a high-capacity system organized around one central processor and a number of peripheral secondary processors. Following a line of research then being actively pursued in various research laboratories (particularly Philips and LM Ericsson), its inventors gave it a switching network consisting of matrices of PN-PN transistor components, so that Aristotle could be described as a purely electronic system. Its central processor, known as Ramses, was an original achievement of CNET's and followed up a first version known as Antinea (1960), which had in fact only been a mock-up intended to serve as a trial run for initial experiments in programming (Antinea's program was extremely limited: only 2,500 instructions).

Developed in 1963 and put into operation by CNET first at Issy-les-Moulineaux and then at Lannion, where it handled the internal telephone service of these CNET sites, Aristotle brought out the technological limitations of using electronic crosspoints. It also provided an opportunity for the first tests of a common channel signaling system, a completely new principle which was then just beginning to emerge, although a little later it was adopted by the CCITT for its Signaling System No. 6 and by ATT for its CCIS system. There is a description of Aristotle in [5].

2.4. The Socrate project [6], which was carried on in close cooperation with French manufacturers of switching equipment, consisted of a switching network based on crossbar components, which was of the traditional type, being derived directly from the French CP-400 crossbar system. The selection of a speech path in the switching network was made under the control of multi-registers testing the availability of crossbar components by means of marking wires. These multi-registers had memories (permanent and temporary) using ferrite cores. Magnetic drum memories were also used as auxiliaries.

The main design effort in the Socrate project went into the development of its control system for which an entirely new method (the work of Pierre Lucas), known as "load sharing" between duplicated processors, was used to ensure that the exchange could operate reliably without interruption.

The Socrate experimental exchange was put into service at CNET-Lannion early in 1965 and kept in operation there for a number of years.

2.5. The main decisions reached by CNET as a result of its experience with Aristotle and Socrate were:

- for the switching network, to abandon the electronic crosspoints in favor of matrices of reed relays in a sealed tube;
- to adopt the principle of load sharing between the processors of the control unit;
- to have the central processor handling all the functions of signal registration, signal translation and call recording for subscriber charging.

3. A second phase of research (1964–1970) leading to the development of industrial systems [3]

3.1. From 1964–1965 onwards, a new phase opened up in CNET's research, involving the development of two new prototype exchanges which were once again decked out with Greek names. These were Plato (in French Platon) and Pericles, which were to take over from the two preceding prototypes, as follows: Pericles for semi-electronic or space-division switching, and Plato for "fully electronic" switching. The Pericles project was undertaken by the various manufacturers belonging to SOCOTEL, while the Plato project was entirely the responsibility of CNET.

3.2. The Pericles project [7,8] led to the installation in 1970 of a first exchange serving 800 subscribers in Clamart, a suburb of Paris, and at more or less the same time the installation of another at the Michelet exchange in Paris, and then a third one in 1974 at Maisons-Laffitte, once again in the Paris suburbs. In 1972, the LMT Company put an exchange of the Metaconta type (see Chapter V-9) into operation at the Roissy-Charles-De-Gaulle airport, the design of which was based largely on the research done for Pericles.

Pericles was the prototype of a system designed to provide a capacity of 30,000 subscriber lines. As far as its switching network was concerned, three successive types of reed relays were chosen: firstly, relays with electric holding, then relays with magnetic holding, and finally Remreeds, which brought the system into line with the progress being made in the United States on the design of these reed relays, resulting in less bulky equipment and reduced power dissipation.

3.3. The design of the Pericles system was of a conventional type and in line with the principles considered at that time most appropriate for space-division switching exchanges.

The situation was quite different for the Plato system designed by CNET under the direction of L.J. Libois. Libois and his associate, A. Pinet,

were wholehearted believers in the principles of time-division digital switching and its long-term advantages. A specialist in PCM systems, Libois had championed the adoption of European standards for those systems based on a "group" of 32 channels ($32 = 2^5$) and 8-bit coding of a speech sample. He realized all the advantages of a digital network in which the same PCM system standards would serve both transmission and switching.

The basic principles of time-division switching were beginning, moreover, to become well known.

Admittedly, the applications so far made had not been crowned with success. The digital time-division system Essex in the United States had only been an experimental research mock-up. In the United Kingdom, the analog-type Highgate Wood project undertaken in 1960 led the General Post Office to abandon time-division switching for an indefinite period. The situation was the same in Germany and Japan. It was then considered that the time had not been ripe for the development of systems capable of competing with the existing ones. The progress of electronic components, however, together with the adoption of firm standards for PCM systems, made it possible to take a step forward in this technology. This was what happened in the CNET laboratories with the Plato system.

3.4. In order to develop a time-division switching system suitable for industrial manufacture, the policy adopted with Plato was to design it as a low-capacity system and apply the simplest possible principles for its architecture, using a minimum of new types of equipment.

The Plato architecture accordingly derived from the traditional design which was almost universal for crossbar systems and had been adopted in particular for the French CP 400 system (on which the design of the Socrates prototype was also based):

– a conventional crossbar line stage (selection/concentration);
– a stage corresponding to the one known in crossbar systems as the "group selection stage", which for Plato was to be time-division;
– associated both with the subscriber line stage and the group selection stage, markers controlled by registers ("multi-registers").

Plato's subscriber line stage was formed by electromechanical subscriber connection units. These units, consisting of crossbar elements, concentrated the traffic and led on to codec devices (for which clear standards had by then been adopted, if only recently) for analog/digital conversion, which in turn were connected to a 32-channel PCM multiplex (2048 kbit/s).

The core of Plato was the time-division switching stage, handling the speech paths in the form of 32-channel PCM multiplex. Equivalent to a group selection unit, this stage was of the type conventionally known (but later) in time-division switching simply by the initial "T" (a T stage enters the 8 bits of an incoming PCM multiplex channel in an incoming buffer store, where they are read in parallel in the time interval which for the outgoing PCM multiplex corresponds to the requested channel). The control memory supplied cyclically the addresses of the buffer stores to be read. It also provided, at every moment, the map of the switching network.

Plato's control system was somewhat different from the system then most in use, in which all the stored program instructions came from a single processor (duplicated for reliability). Plato, in fact, had two control levels:

– the first level was for tasks to be performed in real time, i.e. essentially tasks directly associated with the setting up of calls and disconnection operations at the end of the call, and
– the second level was for tasks with less real-time constraints which required more complex programming: exchange supervision, "defence" devices for diagnosing incidents and locating faults, man-machine interface, etc.

The first level controls were provided by "multi-registers", which were, in fact, programmed "logic and memory elements". The structure of the multi-registers was relatively simple, due to the repetitive nature of the operations performed and the limited number of instructions given. The multi-registers used integrated circuit components of the medium-scale integration (MSI) generation, which had then just ap-

peared. They included in particular components providing temporary stores of 64 and 256 bits. Markers associated with the multi-registers used the same kind of logic and transferred the information between the multi-registers and the switching network of each of the two stages: the subscriber line stage and the group selection stage.

From this brief description, the principles behind Plato's design may be seen by an expert eye to foreshadow two major trends that were to become increasingly important from the late 1970s onwards: decentralization of the control units and the use of microcomputers for that purpose. It will be noted that the early 1970s, when Plato was in the process of being developed, was a time when microprocessors were just beginning to appear and when the very term "microprocessor" had yet to be coined.

4. The birth of the E.10 system and its first steps [9]

4.1. The development of Plato by the CNET research workers and the technical staff of the Société Lannionaise (SLE) proceeded apace. A first exchange was put into service in January 1970 at Perros-Guirec near Lannion and was followed six months later by the introduction of another, larger, a "combined local and trunk exchange" at Lannion. The next stage was the installation of a whole network serving the Lannion area, which was completed in mid-1972 and was to be used for the world's first trial of an integrated digital network. This system was then officially baptized E.10 by the French Administration [4)].

The E.10 was planned to cover a wide range of applications: areas with low telephone density, exchanges for medium-sized towns (Poitiers, 1974, with 15,000 subscribers) and transit exchanges. The digital time-division design of the E.10 system, as its advocates did not fail to point out, was particularly well suited for switching circuits in transit (junction or trunk circuits). Owing to the beginning of proliferation of PCM systems, a growing number of these circuits were digital having no need of the analog/digital conversion required by subscriber line switching. Another advantage offered by time-division digital switching was duly recognized: the principle behind time-division digital switching with only a T-stage did not introduce any blockage in the switching network of the exchange.

We will stop here in our history of the first steps of the E10 system, son of Plato and we shall find its later development in Chapter VIII-4. Although born in 1970 and belonging to the group of systems developed between 1960 and 1974, this system should be ranked rightly among what we call the "second generation of electronic systems", those with time-division as opposed to space-division switching.

5. Steps towards a French-manufactured space-division SPC system

Simultaneously with the research described so far, LMT and CGCT, the French branches of the ITT group, had for their part been busy with work on what they wanted to see become the "ITT system" of space-division stored program control. This work, carried on in cooperation with other firms in the same group, e.g. BTM at Antwerp and ITT traffic engineering research center at Madrid, was based among other things on the lessons learned from the research on the Pericles project discussed above. LMT and CGCT had been much more than just active partners in that project, having, in fact, been the leaders.

The work done by LMT and CGCT led the French Administration in 1972 to adopt, in addition to the E.10 system, a space-division system as a second system intended primarily for the big metropolitan areas in France, and particularly as

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4) Another name, derived from the French pronunciation of E.10, was also used for some years by the CIT-ALCATEL company in marketing the system, which it had selected to manufacture. This was "CITEDIS", the first three letters being those of the company's acronym. (This is the name used in the title of the paper by P. Fritz describing the system in IEEE collection, reference [3] of Chapter V-2).

a replacement for the old and outdated exchanges (e.g. Rotary). This second system was officially designated by the Administration the "E.11". It was meant for local exchanges with a capacity of 10,000 to 30,000 lines, for which the E.10 was too new and not yet suitable. A third official title, the E.12, was kept by the French Administration for a future high-capacity system intended to serve more than 50,000 subscribers or to be used for very large transit exchanges.

E.12 was French first adventure into SPC systems with CIT-Alcatel as the manufacturer. After much delay an E.12 exchange was finally cut over in late 1981 in Paris (Massy-Palaisean) [10].

Despite the endorsement of its official baptism, the infancy and early stages of the E.11 were difficult. There was a great deal of hesitation on the part of the Administration, with decisions going first one way and then the other, before many years later, a considerable number of exchanges appeared with this official Administration designation.

The research leading to the development of what the French Administration called the E.11 corresponded to a system with an ITT name more familiar to switching experts, the Metaconta. In the frantic competition that arose between the major international switching groups from the early 1970s onwards, the Metaconta system, succeeding the Pentaconta crossbar system from the same stable, was one which bore the ITT group's colors. Its development is described in the following Chapter (V-9) dealing with the ITT group's system developments.

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CHAPTER V-9

ITT AND THE METACONTA

1. The ITT Group – a conglomerate by the 1960s

1.1. In Volume I (pp. 261–268) we described the history of the ITT group from its inception in the early 1920s to about the 1960s. Under its founder, S. Behn, who combined business genius with an equal flair for finance and industrial diplomacy, ITT built up a whole empire of telecommunication equipment manufacturing companies in almost every country of Europe. More often than not it did so by taking over long-established businesses which, once within the ITT group, soon thrust their way to the forefront of the industrial scene within the sector.

Expansion in Europe was accompanied by major extension to ensure solid outlets for the group's products overseas: manufacturing subsidiaries were set up in many countries, particularly in Latin America, while telephone network operating concessions were granted in Chile, Cuba and Mexico, and research laboratories set up in the United States.

1.2. After a brief interregnum following Behn's retirement, management of the ITT group passed in 1959 into the hands of Harold S. Geneen, an authoritarian with an acute sense of both organization and financial control. He was often referred to during his 20-year reign as a financial genius: "To him business was not about making products but about making money." [1]

While the wind of a world economy in full expansion was still blowing in the 1960s, Geneen thoroughly transformed ITT's structures and fields of activity, turning his group into the archetype of what has come to be known as a "conglomerate". As a result of hundreds of takeovers in such diverse branches as catering (the Sheraton chain of hotels), insurance (Hartford Fire and Abbey Life), car rental (the Avis chain), industries producing advanced pumping equipment, food industries (Continental Baking), forestry and mineral extraction, ITT became the largest of all the many conglomerates then in existence throughout the world. Trusting to management skills capable of running businesses in any field of activity, the group under Geneen's leadership was constantly on the look-out for fresh opportunities. Legend had it that a new company was drawn into the ITT empire with every working day that passed.

1.3. By the end of the 1960s the telecommunication manufacturing sector, which formed the nucleus around which these developments took place, accounted for no more than 25–30% of the group's activities.

Telecommunication activities are, of course, the only ones with which we are concerned here. It is against this already rather peculiar setting that we shall now describe the no less peculiar and therefore somewhat complicated structures within which first series of space-division SPC systems produced under the ITT flag were studied and built. The equipment went by the family name of Metaconta.

2. Metaconta-related research and research centers

2.1. It was in the mid-1960s, when after ten years' research AT & T (Western Electric) started producing its ESS No. 1 system, that ITT also decided to branch out into the manufacture of SPC systems. The ITT Annual Report for 1966 included the statement that "One of the current major efforts of the System-wide research and development (R & D) efforts is the development of an integrated-circuit, computer-controlled, quasi-electronic telephone exchange that holds promise of being competitive in price with present conventional electromechanical systems, while offering new service features, increased reliability and low maintenance cost."

Although the report refers to a single system, obviously an ideal objective, the group's different research centers in fact made several differing approaches towards achieving that objective. All five of its centers were located in Europe: BTM in Belgium, – LMT, CGCT and LCT in France, – STC in the United Kingdom, – SEL in the Federal Republic of Germany – and SESA in Spain. These acronyms correspond to the companies indicated in Table 1 below.

2.2. After some thirty or forty years' coexistence between these different companies within the ITT group, the relations between them could hardly be better described than by comparison with those between the different countries of the Austro-Hungarian Empire before the First World War: each was highly autonomous, had its own language and traditions and was only loosely linked to the others at the administrative level.

Each ITT European company had a sharply defined national basis. In essence, its market was that offered by the Telecommunication Administration in its own country, with which it maintained close and privileged relations. The Administration would systematically place with the national company a portion of its orders under what was known in the United Kingdom as the "ring" system, one which also operated in equivalent forms in France and Federal Germany and, in a more flexible manner, in both Belgium and Spain.

In each country, therefore, ITT research was closely interwoven with and heavily dependent upon the work being carried out by the Research Departments of the national Administration, particularly in France and the United Kingdom.

2.3. The history of ITT shows that throughout its existence and until the mid-1970s, the company had always had in hand not only one but usually two or three centers engaged in parallel research. This was certainly a weak point even if the situation was imposed by the differing requirements of the group's client Administrations. Yet others have regarded it as a strong point on account of the competition in which the different ITT research centers had to engage each other.

Such had been the case in the 1950s when two separate ITT "houses", as the centers were sometimes called, met eyeball to eyeball, namely:
- the French house of CGCT under F. Gohorel, which favored the production of the Pentaconta crossbar system,
- and, in Belgium, the BTM house which advocated an immediate transition to what was

Table 1

France	CGCT	Compagnie Générale de Constructions Téléphoniques
	LMT	Le Matériel Téléphonique
	LCT	Laboratoire Central de Télécommunications
United Kingdom	STC	Standard Telephone and Cables
Belgium	BTM	Bell Telephone Manufacturing Co. (Antwerp)
F.R. Germany	SEL	Standard Elektrik Lorenz A.G.
Spain	SESA	Standard Electrica S.A.

For the origins of these companies, see Vol. I, pp. 261–265

then known as "electronic switching" (8A and 8B systems, see Vol. I, p. 406),

before the market decided between the two systems and BTM joined the camp of Pentaconta manufacturers.

2.4. Before we proceed further, the research conducted by ITT into electronic switching in the 1960s included work by the French and British companies to meet the requirements of the research departments of the French Administration (CNET) and the G.P.O. respectively. This research, mentioned above in the sections on each country, related:

- in France, to the so-called Aristotle and Pericles systems (see above under sections 2 and 3 of Chapter V-8);
- in the United Kingdom, to the reed-relay TXE series of systems: TXE-1 to TXE-4 (the latter, which was intended for high-capacity exchanges, was studied almost entirely at the initiative of STC) (see Chapter V-6).

These research efforts were often useful as regards the arrangements finally adopted in the design of the Metaconta system. As mentioned earlier, this was particularly true of the principle of load-sharing between the twin processors of the control system. The load-sharing process was promoted by CNET engineer Pierre Lucas and first tested under the Socrate project. The well-known principle in conventional switching, namely the sharing by a number of registers or other control elements of the tasks involved in call processing or routing traffic, was transposed to electronic switching. Two (or in a later period more than two) computers are used "simultaneously" to process different calls. In the event of failure of either computer, the other must be able to handle the total traffic load alone. The advantages of the system include its high processing power in normal conditions and the ability of the computer pair to handle heavy traffic overloads.

2.5. The ITT group's own research was in full bloom in the 1960s and gave birth to an entire family of ITT systems in the No. 10 series [1], i.e.:

- 10AX and 10BX, on which research had been conducted in Paris since 1960 by LCT and CGCT respectively;
- 10CX, developed at Antwerp by BTM;
- 10CXM, developed at Madrid by SESA;
- ZF-2, studied at Stuttgart by SEL

in other words, a total of five specific ITT systems.

The ZF-2 failed to meet with the approval of the Deutsche Bundespost and therefore enjoyed only a short prototype existence before its development was abandoned.

The remaining four systems had so many features in common, particularly as regards their architecture, that a single generic name – Metaconta – was assigned to all of them. It was an ambitious name intended to capitalize on the success of its predecessor, the Pentaconta, again with a Greek patronymic, this time meaning "beyond (and therefore even better than) the (Penta)Conta".

2.6. The Metaconta family placed into production included two groups of systems distinguished by the nature of the basic devices used in their switching network matrices, namely:

- systems using *reed relays* in sealed glass tubes, and
- systems using *mini-crossbars* (designed by CGCT).

Among the different generations of ITT equipment, the former systems were eventually assigned the number 10 and the latter formed the no. 11 series.

2.7. The 10 series with reed relays included the 10C, developed by BTM in Antwerp, and the 10R developed by LMT in Boulogne-Paris.

In accordance with the tradition of having two separate houses designing ITT equipment, the distinction between the 10C and 10R systems lay in the fact that BTM favored an electrical contact for holding the reed relays used in the switching network matrices while LMT favored a magnetic latching arrangement.

[1] As sometimes happens, there must have been a "miscarriage" since the numerical series of the different generations of ITT systems jumps from 8 to 10 and the authors have been unable to ascertain what was or should have been identified by the number 9.

2.7.1. The 10C system, following the entry into service in 1967 of its 10CX prototype at Wilrijk in Belgium, became a standard throughout that country where it was widely used after its 1300-circuit 10C Toll version had been installed in 1973 at Wavre for the trunk service. Again in 1973, APO of Australia installed at Sydney a far larger (12,000 circuits) 10C Toll exchange and equipment of the same type was subsequently introduced at Melbourne and Adelaide.

From 1974 onwards, the 10C system was also widely installed throughout Yugoslavia where it was produced by Iskra, a State-owned factory under a licensing arrangement.

2.7.2. In France, the 10R system had difficulty in gaining acceptance as an officially backed system. A 6000-line centrex exchange was first introduced in 1972 at the Charles de Gaulle Airport at Roissy, outside Paris. In 1974, the 10R went to seek its fortune in Las Vegas in the United States (a 10,000 line local exchange). A dozen of 10R exchanges were installed worldwide. The public version in France was dubbed E11.

2.7.3. These systems used initially 16-bit load-sharing processors developed by ITT and based upon a design by Control Data of a real time control computer. The first processors, developed in Paris LCT Laboratories, were coded ITT-1600. To obtain greater call carrying capacity, later models, always of LCT design, were proprietary 32-bit processors known as the ITT-3200. In 1978 the first of an improved series, the ITT 3202, was added also to improve capacity. The 10C systems with integrated circuit and magnetic drum memories were repackaged and sold in Belgium, Hong Kong, South Korea, and Norway as the 10CN system. The No. 11 system (see below) for France was equipped with the 32-bit version of the improved processor, the ITT 3202. Also a version of the system with wired logic instead of SPC was manufactured and sold in Finland and was known as the 10F system.

2.8. The 11 series, i.e. exchanges with mini-crossbar switching network, included:

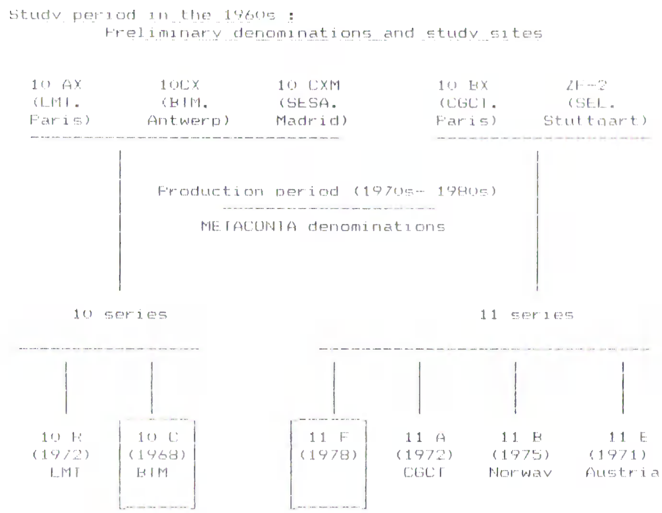
- the 11A produced by CGCT of Paris and installed for the first time at Rabat (Morocco) in 1972;
- The 11B, used in Norway from 1975 onwards for small-capacity rural installations and manufactured by Standard Telephone og Kabel Fabrik, Oslo (ITT's Norwegian company). Although it used the ITT mini-crossbar, this was not an SPC system but one based on wired logic;
- the 11E, installed in Austria by ITT Austria Telephon und Telegraphen G.m.b.h. from 1971 onwards [3];
- the 11F (see section 3.3 below) widely installed throughout France after 1978 (starting with the Segur exchange in Paris).

The mini-crossbar or miniswitch which characterized the series 11 Metaconta exchanges – and received the name of Metabar – was designed in Paris by CGCT engineers. It represents a typical example of the mini-crossbar trend so much in vogue in the 1960s and was offered as a competitor of matrices consisting of reed relays in sealed envelopes combined within one and the same module. The Metabar is a mechanical device so ingenious that its operations are difficult to describe. A succinct description is, however, given in [4].

One of the features of the Metabar was the *mechanical latching* of connections once they had been set up.

2.10. Similarly, connections in the reed relay matrices of the Metaconta 10R were *magnetically latched*.

Both mechanical and magnetic latching are unlike electrical latching in that the latter requires a third wire in the switching matrix in addition to the two speech path wires. That makes for far more compact switching matrices and much cheaper production costs; and also less power consumption and dissipation. However it is necessary to know the switching network configuration state for defining the free paths available for establishing the connection, no more by a



METACONTA FAMILY

In the two Boxes, the two types (10 C and 11 F) which were the most important in line production.

Years quoted inside brackets under the Metaconta series are the ones of the first in-service implementation

Fig. 1. The different versions of the Metaconta

third wire, but by mapping in the central processor memory.

The latching feature requiring no third wire was regarded at the time as sufficiently important that in the early 1970s, before the 10 and 11 series had become differentiated, another generic name – Metaconta L (L for latching) – was given to all such systems. It is under this name that the configuration of the family's systems and the essential characteristics of their hardware and software are described in [5]. In it, the interested reader will find, in wonderfully condensed form, full information on Metaconta architecture.

2.11. The Metaconta family was clearly a large one and it is only too easy to get lost and confused among all the names of its offspring. Fig. 1 gives a chronological (or perhaps genealogical) table of the different versions and may perhaps help the reader to sort matters out.

It would be harder still to decide infallibly on the paternity of the different versions, even given only a few of the many names of those who presided over their design. However, mention should be made of:

– H.H. Adelaar, S. Kobus and M. Verbeeck in Antwerp,
– S. Kobus, A. Kruithof, A. Regnier and J. Trelut in Paris, who were among the leading designers and initiators of these systems.

3. The deployment of Metaconta systems

As happened in the case of the ITT Rotary and Pentaconta systems, the fate of the different versions of the Metaconta family depended far less on considerations relating to their specific technical characteristics as on reasons that had nothing to do with the latter's merits. The decision to purchase this or that ITT system was usually a reflection of national industrial policy and even, in some countries, a matter of pure politics in the strictest sense of the term.

3.2. The most typical example of this occurred when the French Administration adopted Metaconta 11F as its standard system in 1975. We shall describe this case in some detail in Box A since it typifies how a technical choice is ultimately based on exclusively political considerations.

3.3. After consultations which started in 1975 and are described in Box A, the French Adminis-

tration's choice of space-division switching for its standard systems was eventually narrowed to two:

- the Metaconta, from then on produced in parallel by CGCT which had remained within the ITT group, and by Thomson which had taken over LMT;
- the AXE, manufactured by Thomson which had also taken over Ericsson-France.

The version of the Metaconta decided upon was known as the 11F. This again was a hybrid in that it largely used Metaconta software developed by LMT and at the same time the CGCT-developed Metabar mini-crossbar. There were probably two reasons why the Metabar was chosen for the 11F system, namely:

- the fact that, having been developed within CGCT, it was of an entirely French design. Thus the production of switching matrices for the French Metaconta was not dependent on foreign know-how and components as in the case of reed-relay matrices;
- ITT won a consolation prize in that royalties for the use of Metabar matrices on export

Box A

A typical example of how political considerations can influence the choice of a switching system

The Metaconta 11F in France

1. In the early-1970s the telephone situation in France had gone from bad to worse since the late 1950s and there was a public outcry about it. On average, it took roughly a year for a new subscriber to become connected and the scantiness of the service itself "was disrupting business at the economic level, acting as a brake on the industrial decentraliztion sought by the government and hitting the individual in terms of time wasted, fatigue and sometimes insecurity" [6].

Official action to tackle the problem took a new turning in 1974 when the newly elected President of the Republic boosted matters and opened what some have referred to as the golden age of the French telephone. The telephone became the centre of a programme of priority action and 140 billion francs (worth US$28 billion at this time) were invested between 1975 and 1980. The number of subscriber lines, which stood at 4 million in 1970, passed the 16 million mark in 1980 [7].

This considerable effort was accompanied by thorough structural changes within the Administration as well as in France's telecommunications industry.

Within the Administration, the Directorate General of Telecommunications (DGT) won the self-managing role it so long sought and gained access to financing other than that dispensed by the State, with the right to borrow both at home and abroad. Indeed, the DGT resorted heavily to foreign loans and for several years was to become France's largest investor. Its management came increasingly to resemble that of a large company: its administrative structures were decentralized and the telecommunication services lost their bureaucratic approach to users, adopting a more business-like and even a more companionable attitude.

2. More germane to our purposes is the upheaval which took place in the structure of the French switching industry in 1976.

An industrial strategy was worked out and implemented almost aggressively by the DGT's Industrial and International Affairs Directorate (DAII). It had a two-fold objective, namely:

- for the very large amounts of equipment programmed and to be ordered, to choose switching systems which not only would be of a modern type but would also offer extensive proven references in operation – i.e. space-division systems – without having to await the arrival of the E 10 time-division system which was being developed by CNET but had not yet reached full maturity or the stage of production of large capacity exchanges;
- to ensure the "Frenchification" of the industrial groups producing the equipment, in other words to see to it that they were wholly French in capital and not controlled by foreign companies.

Box A (continued)

In 1975 there was a vast international call for tenders for an initial supply of one million lines of the type chosen. To meet the occasion, French manufacturers and foreign partners joined forces (see Table 2) and entered into licensing arrangements.

Table 2
Partnerships considered for the 1976 French call for tenders

Foreign partner and system offered	French partner
NEC Japan – D10	CIT – Alcatel *
Northern Electric – SP 1	Thomson
LM Ericsson – AXE 10	SFTE **
Siemens – EWS	SAT ***
Philips – PRX	TRT ‡

* CIT-Alcatel: The "Compagnie Industrielle des Téléphones", representing the telecommunications branch of the "Compagnie Générale d'Electricité" (the French CGE group).

** SFTE: Société Française des Téléphones Ericsson, often simply known as "Ericsson-France"; this was a subsidiary in France of the Swedish LM Ericsson group.

*** SAT: Société Anonyme de Télécommunications (engaged essentially in transmission but also in the manufacture of private switching plant).

‡ TRT: A French subsidiary of the Dutch Philips group.

The Metaconta, offered jointly by LMT and CGCT, both French companies belonging to the ITT group, was naturally among the front runners in the competition and, together with the AXE and the PRX, was one of the systems most warmly received by the French Administration.

3. The second stage of the reshuffle was to create within France's switching industry a second and specifically French pole alongside the already French owned CIT-Alcatel. As one of the leaders in the French electronics industry, Thomson-CSF was a candidate for the role: until then it had remained aloof from switching under market-sharing agreements that it had signed earlier with CGE's CIT-Alcatel company but which had just expired.

After hard wrangling with ITT's American management by a very small French team drawn from the highest government circles ["a game of poker" some contemporary commentators called it, though more critical minds have since referred to "drawing room discussions"], ITT sold to Thomson-CSF its LMT company but kept CGCT on seeing the Metaconta system recognized as France's chosen system. At the same time, Thomson-CSF took over Ericsson-France so that the AXE 10 system also gained acceptance in France. Although under the majority control of foreign parent companies, both LMT's and Ericsson-France's shares were quoted on the French stock exchange while those of CGCT were not. This consideration facilitated a kind of takeover bid, even if with one hand somewhat forced, and was certainly not unconnected with the choice eventually made.

markets had to be paid to CGCT and therefore to the ITT Group.

For some years the 11F system was, if not the French Administration's charger, at least its carthorse. It was usually used in large exchanges with a maximum nominal capacity of 64,000 subscribers in Paris and other major French cities where it replaced the Rotary exchanges that were becoming obsolete. Almost 2 million Metaconta 11F lines were in service or on order in France by 1979. As the No. 1 system used in France, it is described in detail in a special chapter of Grinsec's work [4].

3.4. One aspect of the Metaconta's competitiveness stemmed from the considerably smaller work force needed for producing it, an advantage which incidentally was shared by its counterparts of the same generation. As told in [8], a book which also gives a detailed description of the

processes used in French factories for manufacturing the Metaconta 11F, the production time of eight hours for one Pentaconta line was reduced to four and a half hours for one Metaconta line. There were two reasons for this considerable reduction in the manpower needed, namely the design of the system itself and the extremely high degree of automation of the different manufacturing stages involved.

3.5. Altogether, over 7.5 million Metaconta "equivalent" lines of different versions (6.3 million "mainlines" and 1.4 million of trunk circuits) were already installed in 1975 in a large number of countries. Besides Belgium (10C), France (11F) and Norway (11B), the main host countries included Yugoslavia, Indonesia, Egypt, Argentina, Colombia, Spain, Finland, Hong Kong, South Korea, Morocco, Mexico, Singapore and Taiwan, not to mention a number of installations in Illinois and Texas, in addition to the one already mentioned in Las Vegas in the United States.

Indeed, the Metaconta family offered a whole range of exchanges including some for trunk and international purposes (some of which were installed in, for example, Australia).

The system also offered all the facilities (abbreviated numbering, etc.) characteristic of the first generation of SPC exchanges. For instance, it was thanks to the Metaconta 10R installed at Roissy-Charles de Gaulle Airport near Paris in 1972 that Parisians departing for a flight became the first people in France to discover the merits of the push-button telephone which had already been a common feature in the United States for over ten years.

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CHAPTER V-10

LM ERICSSON – THE AKE SYSTEMS AND BEGINNINGS OF THE AXE FAMILY

1. LME, a company which has to export switching equipment all over the world [1]

In the switching industry, LM Ericsson (referred to hereafter by its initials LME) is one of the oldest established companies, having celebrated its centenary in 1976. It is distinguished by two features in particular:

- its activities, though manifold, are overwhelmingly concentrated on the manufacture of telecommunication and especially telephone equipment;
- it works mainly in the export market, since more than three quarters of its industrial products go outside Sweden (where the company's headquarters and its main establishments are situated).

Within the area of telephony, LME has traditionally specialized in the manufacture of switching equipment, which accounts for the greater part of its sales. This explains why the company very early took an interest in the development of electronic switching. By 1954, it had set up a laboratory model, known as EMAX, using pulse amplitude modulation (PAM), cold cathode tubes as switching network elements and diode-based logic (see Chapter II-5, section 3–4) [1a].

Simultaneously, LME introduced elements of electronic logic in various parts of its systems, for instance in the voice-frequency signal receivers which began to appear in the early 1950s, and in the markers of its latest crossbar systems to replace relay logic.

2. Electronic switching experience acquired by LME in the United States [1b]

In 1951, LME took over an equally long-established American switching company, North Electric [1], situated in the State of Ohio, which ran a large electronic section geared to military applications. In 1959, North Electric bid successfully for a contract to supply a series of all-electronic exchanges for US Air Force tactical communications system. These exchanges based on the analog time-division (PAM) switching principle, were to provide four-wire switching between a few hundred lines and a small number of long-distance circuits. Manufactured in the United States, their design was mainly the work of the Swedish engineers of LME, who were able in this way to gain valuable experience in electronic switching.

3. Parallel development work on SPC exchanges undertaken in Sweden by LME and by the Swedish Administration [1b]

3.1. In Sweden, at the same time as LME, the Swedish telecommunication Administration, Televerket which manufactures its own switching and other equipment in its Industrial Division, known as TELI, had also begun to explore ways of introducing new electronic components into switching equipment. In 1956, an agreement was reached between Televerket and LME to set up a Joint Electronic Council to coordinate shared

[1] See page 112 of Volume I about the origin of the company, named after an engineer, one of the distinguished precursors of automatic telephony. Throughout its long history, North Electric passed from hand to hand and from one company to the other. It was part of the LME empire for 15 years, from 1951 to 1966, before belonging to United Utilities (a holding company for a group of large "independent" telephone companies in the United States), and later, in 1972, to ITT.

development work, with Televerket concentrating on space-division and LME on time-division systems.

3.2. In the early 1960s, the Joint Electronics Council, fully informed of the progress achieved by ATT with the development of SPC exchanges, decided to pursue a unified approach and to produce a prototype exchange of the same SPC type using metallic cross-connection points in its switching network, like its American counterpart. Televerket and LME, however, each adopted a different type of device for their switching network:

- LME used its code switch, a very specific type of coordinate switch which it had developed since 1957 and which may be considered as a precursor of the various kinds of minicrossbars which were very popular between 1965 and 1975. In the code names used to identify LME systems, the letter K following the first letter (always an A for Automatic) is used to denote crossbar or SPC exchanges equipped with code switches (see pp. 430–431 of Volume I concerning the development of the code switch and its applications);
- Televerket opted for a magnetic latching version derived from its traditional crossbar switch.

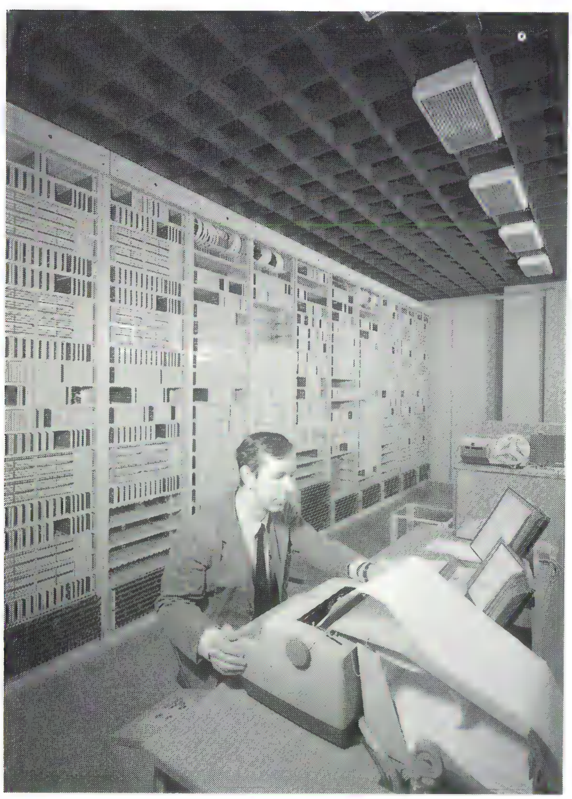


Fig. 1. The Tumba exchange (1968), the first SPC exchange in the world outside the United States.

In the town of Tumba, south of Stockholm, LME installed its prototype exchange. After overcoming a number of difficulties with programming, with which it had little experience, LME finally opened the Tumba center, known as AKE 11, in 1968 (4,300 subscriber lines and 640 circuits) (Fig. 1). Another exchange of the same type, (AKE 129), but with four-wire speech paths, was brought into service at the same time on special order by the Swedish Air Force. These two SPC exchanges were apparently the first in the world to be brought into service outside the United States.

The exchange produced by Televerket, the A210, was installed in 1968 in Storangen, shortly after the Tumba exchange, but remained purely experimental.

4. An SPC system, the AKE 13, for long-distance national and international transit centers [2]

4.1. The AKE 13

In order to exploit the experience it had acquired with the development of the Tumba SPC exchange and its military twin unit, LME decided on a clear-cut course of action, which fitted perfectly with its general policy of being a major world supplier and which consisted in producing transit centers for the national and/or the international service. The market for this type of equipment rested on the most exacting requirements of an ideal group of customers. Long-distance traffic was growing steadily (by some 15 to 25% a year) and required increasingly sophisticated switching techniques, including service supervision and alternative routing, while

being subject to difficult constraints arising from the multiplicity of signaling systems with complex signal transfer interfaces. SPC technology was best suited to cope with the delicate problems of these large transit centers.

In the LME series, these exchanges were code-named AKE 13 (K for code switch and E for electronic, referring to control by a group of processors: initially eight pairs of duplicated processors). Once again, the town of Rotterdam in the Netherlands had the distinction in LME history of being chosen to receive the first operational AKE 13 exchange system, in 1971 [3], just as it had received the first LME crossbar (ARM) transit exchange in 1952 (see Volume I, p. 424). The AKE 13 in Rotterdam had 2,400 incoming trunks and 2,400 outgoing trunks. A second and larger exchange was opened in Copenhagen in 1974. This was the first of a whole series of units supplied to a number of countries, including Sweden, Finland, Mexico, Norway, Italy, and Australia, where the AKE 13 delivered to the OTCA (Overseas Telecommunication Corporation, Australia) was the first exchange of this kind to use the CCITT international signaling system No. 6. By 1976, there were 26 AKE 13 systems in operation, and by 1981, the number had risen to 37, installed in 10 different countries, including the United Kingdom with its international center (Thames) in London [4].

In history of SPC switching, the 1971 Rotterdam exchange was the first to use multiprocessor distributed control, a technique which was to spread in the 1970s. Another fundamental characteristic of the AKE 13 system was its modularity both in hardware and software.

4.2. AKE 13 makes it way to America with a new code – ETS4

United Telephone purchased the North Electric Co. in the United States from LME in 1966. Nevertheless, North acquired the rights to develop a version of the AKE 13 for the US market. Starting in 1969, this version of the system was called the ETS4, for Electronic Toll Switch 4-wire [5]. The first office was cut over in Lexington, Kentucky, in 1974, followed by 10 additional offices sold to US independent telephone companies until 1980.

5. The ARE system: SPC equipment grafted onto traditional crossbar systems [6]

In the potential market for LME switching equipment, AKE 13 SPC transit centers represented an outlet which was undoubtedly significant, but which in the longer term was bound to be modest compared to the market for local exchanges. In the course of the 1950s and 1960s, LME in Sweden and through its subsidiaries in a score of countries had produced a considerable number of crossbar exchanges with 23 million LME crossbar lines installed by 1977. Most of these exchanges were of relatively recent manufacture, half of them having been brought in service within the last six or seven years. Obviously it was out of the question to replace these crossbar exchanges with SPC systems, despite the advantages of the latter both for service operators and for their customers.

There were two types of factors which prompted LME to develop a new system:

- industrial factors, relating to LME and to the company's considerable investment in production facilities for crossbar equipment, both in Sweden and in countries abroad;
- commercial factors, relating to LME's main customers, i.e. public telephone service operators, who were not keen to replace relatively new equipment.

This new system, known as the ARE (the E at the end of the code name replacing the F of the ARF crossbar system), combined the traditional LME crossbar systems with SPC technology. It was designed to serve two purposes:

- to supply new exchanges offering subscribers SPC facilities while still making use of most of the industrial plant set up to produce crossbar equipment;
- to modernize existing crossbar exchanges, particularly local exchanges [7].

The introduction of SPC techniques into crossbar equipment affected one part of the exchanges in particular, the registers, where complex functions such as the reception, storage, analysis and translation of subscriber data and circuit signaling are concentrated. One advantage of full register organization in an exchange was that it could rather easily be replaced by a subsystem (which became known as ANA 30) without modifying the structure of the exchange's other subsystems.

The ARE system is thus equipped with an SPC subsystem in which a large number of registers (initially 30, later extended to 60) can be controlled by a single processor. The latter's program controls not only the registers but also signal receivers and senders. The operation of the processors is combined on a time-sharing basis with that of the registers under their control. Each register is allocated a fraction of time corresponding to the division of a certain time interval (8 milliseconds), the processor's basic working rate, by the number of controlled registers. For a normal subscriber traffic load, a 10,000-line local exchange was usually equipped with two or three processors (with stand-by facilities).

Each processor was equipped with integrated circuit logic, program memories, and associated data memories consisting of:

- a "subscriber" memory containing all data concerning the allocation of directory and equipment numbers and details of facilities offered to the subscriber;
- an "analysis" memory containing routing (including alternative routing) and signaling data;
- an "abbreviated dialing" memory to translate the digit or the two digits of the abbreviated number sent by the caller into national or international numbers.

The first ARE exchange was introduced in November 1973 as an extension of a local exchange in Aarhus in Denmark.

Two types of exchange were produced in the ARE series; the ARE 11 for local exchanges and the ARE 13 for tandem or transit exchanges.

By 1979, six years after the system had been first introduced, about 1.5 million subscriber lines were using the ARE 11 system. About two thirds were modernized exchanges, and the other third were new. Most of the modernization of exchanges with ARE 11 was carried out in three countries: in Australia chiefly, where exchange modifications had been studied in close consultation with the Australian Administration and LME's subsidiary in Australia (LM Ericcson Pty. Ltd.), in Denmark and in Saudi Arabia. Another fifteen countries had installed or were installing ARE 13 transit exchanges, the three main clients being Argentina, Ireland and Saudi Arabia [8].

7. Foundation of the ELLEMTEL Company and launching of the AXE system

In April 1970, with a view to closer cooperation, LME and Televerket set up the Ellemtel company to carry out research and development work on electronic exchanges and digital transmission. Ellemtel, whose full title is Ellemtel Utvecklings AB, was set up in the form of a joint stock company in which the parties hold equal shares.

The research on a new SPC system, the AXE system, was then undertaken by Ellemtel, LM Ericsson being responsible for manufacturing and marketing. The characteristic letter X appearing as the second letter in the title AXE indicated that the system was generated not by LME, but by Ellemtel.

The AXE system, research on which began in autumn 1970, as soon as the Ellemtel company was set up, was designed (Fig. 2) in the first place for local exchanges with medium or large capacity. Only systems of this type with space-division switching will be dealt with in this section, because they are the ones that belong to the period under consideration. For the same reasons of chronology, these space-division versions of high-capacity local exchanges are also the only ones mentioned in [3] of Chapter V-2, which is our basic reference in this Part of the book [2].

[2] The AXE system is the most recent of all the systems described in [3] of Chapter V-2 and accordingly is the only one not to be given a full bibliography after its description like the others in that reference.

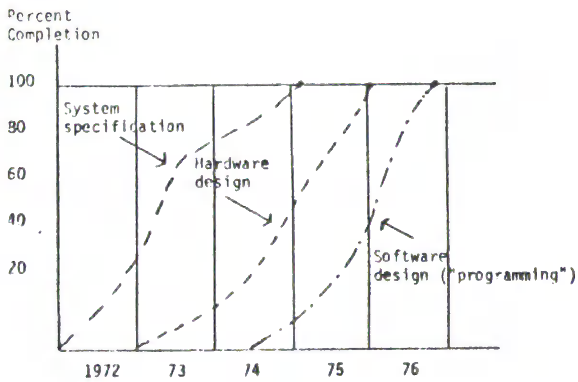


Fig. 2

From the very outset, AXE was designed to be a system that would evolve, so that it could be used for different types of exchanges and optimized for time-division digital switching. We shall therefore meet AXE again among the digital systems in Chapter VIII-9. We confine ourselves here to a mere outline of the AXE architecture and of the different phases of its initial appearance on the world market in its space-division version.

8. Architecture of AXE [9,10]

8.1. Its modular character

The application of a modular (physical as well as electrical) design principle had already been very much a feature of the AKE and ARE systems. This principle is to be found in a more marked form, in the architecture of the AXE system, characterized by a systematic modularization of both its hardware and software. Kurt Katzeff and John Meurling were among the designers of the AXE system. They had already been among those responsible for developing the Tumba exchange and then the AKE and ARE systems. There were four reasons which led them and LME to apply the principle of modularity in the most systematic and rigorous fashion:

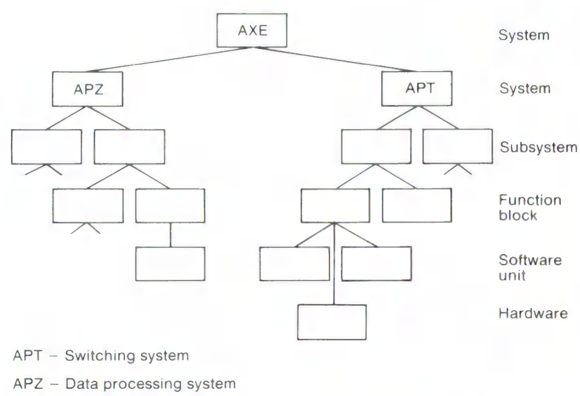
"i) Great freedom to engineer each exchange individually with regard to application, size and functional requirements.

ii) A system easy to understand and to handle. Such handling as training, planning, fault finding, etc. can be treated in one subsystem at a time.

iii) A system which can live in a future environment. The introduction of common channel signaling, digital switching networks, centralized subscriber functions, remote controlled subscriber switching networks, etc. is made easy.

iv) Possibility of introducing new technology, e.g. new types of memories, electronic switching matrices, without changing the basic system structure." [10]

In the architecture of the AXE system, the assembly of the different modules corresponds to a general structure consisting of four levels forming a strict hierarchy: system, subsystem, "function block" and "function unit" (Fig. 3).



APT – Switching system

APZ – Data processing system

Fig. 3. AXE System Structure Levels

In the AXE system, a module can be considered as an abstract entity, a "black box". It is designed to perform a function or group of functions, independently of its actual construction. It is only at the lowest level of the hierarchy, the functional unit, that we find the basic elements designed for manufacture of the hardware. These basic elements are what may differ in the successive versions adopted for implementation of the system.

The "black box" module is essentially defined by its interfaces – hardware and software – with the other modules, and not by its internal organization. The programming of the system itself is organized in accordance with a breakdown of the software into unit programs which incorporate instructions and data. The determination of the "software signals" to be exchanged between modules is one of the key elements in the system design.

8.2. Structure of the system (in its initial versions)

The structure of the AXE system breaks down into two parts, one for switching and one for control.

In the first part we find the following subsystems:

– subscriber switch subsystem (SSS);
– group switch subsystem (GSS);
– trunk signaling subsystem (TSS);

and various subsystems for control and supervision of the speech and path connection, charging, defence, and traffic monitoring.

In the second part, the control part, we distinguish two levels, each comprising its own subsystem:

– centralized control, provided by two "CP" processors operating in microsynchronism and performing the traditional "executive" and "scheduler" functions together with the complex programming functions;
– decentralized control, assured by specialized and duplicated miniprocessors performing simple and repetitive functions. These miniprocessors, which can be described as peripheral, are known in LME terminology as "regional processors" (RP). They operate cyclically under the control of the centralized command (CP), to which they are connected by buses. A 10,000-line exchange may use 15 to 20 pairs of RPs.

8.3. Software of the system

The design of the AXE system, unlike that of most previous systems, belongs to a period when software was beginning to come to the fore and take the lead over hardware. Furthermore microprocessors were also used in this system for the first time to replace logic so that the regional processors could be similar in design. The programs for the different microprocessor applications made them functional for the particular needs of each peripheral unit. In AXE, the hardware being entirely passive only performs very simple functions. All decisions are made by the software. The peripheral software performs simple and repetitive tasks which are machine-time-intensive. The central software performs all tasks of coordinating and relating functional blocks of the more complex functions (e.g. translation, charging, operation and maintenance).

To program AXE, LME developed a sophisticated language specifically aimed at switching applications. This language, which was derived from the Pascal language, originally known as Eripascal, was later to be called Plex. This was one of the languages which subsequently served as the basis for the specification of CCITT's CHILL language. Additionally the man-machine language developed by LME was among those which exercised a considerable influence on the development by the CCITT of its standardized MML language, the Swedes having been particularly active in that international project.

The AXE software was produced in accordance with all the rules of software engineering: an object program in machine code was obtained by means of a programming system (APS 210) from a "source" program written in Plex.

9. First steps of the AXE system [9]

9.1. Receiving the series number 10, it is with the name "AXE 10" that the system carries the flag for LME. It made its début early in 1977, when the Sodertalje exchange near Stockholm was put into service. The installation of this exchange in 1976 was one of the events by which LME celebrated its centenary.

The switching network of an AXE exchange in its space-division versions consisted of stages made up of reed arrays (8 × 8) with electrical

control and holding. The subscriber switch system (SSS) unit of AXE 10, with three stages, had a capacity of 2,048 subscribers. The group switch subsystem (GSS) consisted of two symmetrical groupings (each with three stages) for reliability. The AXE system was inherently designed from the beginning so that the reed relay blocks of the GSS subsystem could later be replaced by PCM digital switching.

Even before its group selection switching was digitized, different versions of AXE were developed for local, tandem and transit exchanges. Ten years after the first installation at Sodertalje, LME had put into service more than 8.5 million lines using AXE in 65 different countries. The greatest number of lines installed in AXE 10 (analog versions) outside Sweden were in France (exchanges manufactured in France), Saudi Arabia, Denmark and Kuwait. Just for the record, the existence of versions derived from AXE for telex circuit and data transmission switching which were designated AXB is to be mentioned.

9.2. The development of the fully digital versions of the AXE and of their successes will be covered in Chapter VIII-9.

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CHAPTER V-11

IN THE NETHERLANDS, PHILIPS' PRX SYSTEM

1. Philips Telecommunicatie Industrie and its first steps in switching

The activities of Philips Telecommunicatie Industrie in the telecommunication field represents only one of some fifteen sectors covered by the giant multinational Philips group. In telecommunications, Philips Telecommunicatie Industrie, sometimes referred to as PTI, is better known simply as Philips, even though this not strictly accurate appellation is not its official name and may lead to confusion with the parent group. For the sake of clarity and to observe the more common usage, that is the name we shall mostly use in this section (except in the following few passages where it is useful to draw a distinction between PTI and the Philips group). It will be noted that PTI and its Dutch establishments have their headquarters at Hilversum and are thus separate from those of the parent company at Eindhoven – indeed, far from them, at least as distances in Holland go ...

Unlike most if its competitors in the telecommunication industry, PTI is fairly young and was founded only after the Second World War. After commencing its switching activities by manufacturing Siemens-type step-by-step exchanges to replace those destroyed in the Netherlands during the War, PTI designed and developed a family of electromechanical systems (rapid step-by-step systems of the uniselector type – see Volume I, pp. 229–231) which from 1955 onwards were installed in several countries, though mostly in Holland itself.

However, the Dutch network never has been a private reserve or, to use a more diplomatic expression, a captive market of PTI. Far from it – it was even a highly competitive market: ITT, owing chiefly to the proximity of its Belgian subsidiary BTM at Antwerp, and Ericsson which had always supplied equipment in certain areas (Rotterdam) of the Netherlands, were among several very serious competitors.

Philips (the parent company) had since the beginning of the century been very active in the production of radio components and was chiefly known for its electronic valves. Even before the Second World War, research had been planned at Eindhoven for using electronic valves in the design of switching devices. After the War, the Philips group became one of Europe's most active poles in the development of what was later known as electronic components, i.e. transistors and, later, integrated circuits. At the same time the parent company initiated a branch for the development and manufacture of computers.

Within this general line of technological development, Philips Telecommunicatie Industrie started in the mid-1950s to conduct experimental research on exchanges with "electronic crosspoints", provided by electronic gates consisting of solid-state components. For this purpose, PTI built a laboratory-model SPC exchange, known as the ETS I, and having a switching network consisting of PNPN units [a paper describing the ETS I was given at the 1960 ISS in London in [1]]. Besides the ETS I laboratory model, two other models, this time as experimental exchanges and known as ETS II and ETS III, were installed in the Netherlands and Denmark in

1967. They required low-current telephone sets so that each subscriber on the appointed cutover date had to change from their old to their new telephones. The results obtained using PNPN components were not, however, up to expectation. Although very high, the ratio between the open-state and closed-state impedances of PNPN gates was in no way competitive with the infinite impedance obtained using a metal contact, and thus gave rise to difficulties of crosstalk and speech-path loss.

The programming experience acquired in the building of the ETS I was not wasted, however, and PTI put it to use for building store-and-forward switching system for telex netowrks. This was the DS 714, introduced in 1964, which became a huge commercial success.

2. Research by Philips for an SPC telephone exchange

The American success of SPC switching, duly recognized since the mid-1960s, could obviously not fail to catch PTI's attention, particularly since the company already had some experience in this new technology and, in addition, belonged to a group heavily involved in the other two branches of the electronics industry, namely, components and computers. PTI therefore started to research and develop an SPC telephone system with a switching network having, in line with general practice at the time, crosspoints provided by reed relays. A special type of reed relay was studied and developed by Philips for this purpose.

Rapid research gave way to the construction of a first prototype exchange which, upon installation at Utrecht in 1972, was already capable of handling public traffic during tests conducted in cooperation with the Netherlands Administration.

3. Early days of the PRX system

The Administration approved the system in 1973 after assessing the performance of the Utrecht exchange in comparison with that of other systems then available. Philips then baptized its system the "PRX" [1]. The PRX system soon became widely introduced within the Dutch network: by 1979, i.e. six years after the first PRX exchanges had been brought into service, there were 170 such exchanges in the Netherlands serving a total of 1.25 million subscriber lines. The PRX system was used in the Netherlands essentially as a local exchange but could also serve in some towns as a tandem exchange since it was capable of switching overflow traffic via alternative routes.

The PRX system was a successful export product from the outset. Following fairly small installations (first in Jersey island, and later, in Indonesia, Egypt, India and various Latin American countries), it was chosen, together with Ericsson's AXE system, by the Kingdom of Saudi Arabia in 1977 as a switching system for its own network. In what was merely an initial order, the Saudi network modernization plan covered orders for the supply and installation of some 500,000 subscriber lines. Having won the Saudi contract in the face of stiff competition, Philips and L.M. Ericsson shared the switching orders about equally: the PRX system was ordered for very many medium- and small-capacity exchanges (320,000 lines), while the AXE system was installed in a few exchanges having large numbers of subscribers and in tandem or transit exchanges. When these initial orders had been fulfilled within five years, Saudi Arabia (1.3 million lines in 1986) went on offering a prime market for the installation of both the PRX and L.M. Ericsson's AXE exchanges.

A digital version of the PRX system appeared in 1981–1982. A series of processor were designed for this system indicating PTI' store interest in the computers and software [2]. But the system did not go in industrial production after PTI took the decision to merge its telephone switching activities with those of AT&T and to set up a

[1] A designation which replaced those of "205", "405" and "XR" used for the different models built during the research phase.

joint APT (AT & T Philips Telecommunications) firm to develop an "European-type" version of the American ESS No. 5. The designations "PRX-A" (A for analog) and "PRX-D" (D for digital) were sometimes used to distinguish between these two types of systems.

4. The PRX (PRX-A version) architecture [3,4]

The PRX system was designed to operate in widely varying applications ranging from low-capacity local exchanges (including portable exchanges in containers) to local exchanges with a capacity of up to 40,000 lines and to long-distance tandem or transit exchanges. The middle of the range included combined local/tandem exchanges.

4.1. The PRX switching network is of the classical multi-stage link type and is divided into two blocks: the three-stage Line-Link Frame block (equivalent to a subscriber sub-system) and the six-stage Trunk-Link Frame block (equivalent to a "group selection" sub-system). The setting-up and release of connections are effected by markers attached to each of these two blocks. The status of the speech paths in the switching network is mapped in the memory of the central control unit.

High-speed glass-sealed minireed relays are used as crosspoints, in switching matrices of 8×8 relays. For local exchanges, the reed relays provide three contacts: two for the speech path, the third one being used during the marking process and to hold the relay electrically.

4.2. The central control unit (CCU) comprises two Philips processors (TCP 18 or TCP 36) operating instruction-synchronously in a dual mode and continuously compared for proper performance. Ferrite core memories are associated with the active one of the two processors and store the operational software programs and the relevant data.

The main task of the CCU is to control and schedule the switching functions (scanning, initiating the establishment of connections or their release, etc.). Its other tasks are to control the system configuration, to be the interface with man/machine devices, and to perform a number of monitor functions (traffic measurements, subscriber metering, etc.).

In the case of very heavy traffic/great capacity exchanges, the exchange plant itself may consist of two (or even three) CCU units (i.e. pairs of processors) which share the exchange load, each one operating singly for a given portion of the switching network.

4.3. The PRX software has a modular structure. The operational program comprises a group of independent sections, known as "facility modules" associated with service facilities, which can be added, deleted or modified to satisfy specific application requirements. The exchange parameters are stored in a memory giving a description of the characteristics of the particular exchange and in the form required by the operational programs. Three distinct boundaries exist in the operational programs: they delimit the call-processing function, the man/machine function and a hardware supervision function (a "defense" function producing interrupt requests and fault diagnoses).

PRX software production is generated by a Project Generation System consisting of a number of specially developed programs that compile and maintain program libraries, generate programs and data structures required for the operation of each PRX exchange and simulate a telephone environment for testing generated operational programs.

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Part VI

The success of the SPC concept for the design of switching systems

CHAPTER VI-1

TYPOLOGY AND ANALYSIS OF SPC 1ST GENERATION

1. Introduction

As described in Part II electronic switching captured the imagination of many inventors and institutions after World War II. There were many early experiments, small laboratory models or PBXs. While most of these functioned successfully, the cost and indetermination in reliability of semiconductors were often considered a bar to proceeding with the development and production of larger electronic switching systems.

The development costs for electromechanical switching systems had been relatively small, for example in the order of several hundred thousand dollars (US). The efforts of AT&T Bell Laboratories were observed with much interest. Not only had their efforts taken a new direction, i.e. the use and exploitation of stored program control (SPC), but the development costs were increasing rapidly.

No companies or administrations were willing initially to make the large financial and personnel commitments that were ascribed to AT&T. Many were not convinced that their approach was the most suitable or needed for commercial telephone exchanges. In the past decade (1950–1960), the crossbar and EMD technology was for most manufacturers fairly recent and therefore a new technology was not needed. Administrations found that exchanges in these systems functioned satisfactorily and improved maintenance expense. The new services that were promoted as attributable to SPC offered little incentive to those administrations where telephone service demand was great and far from universal.

2. Many successes – but which took time for confidence

A number of successful space-division electronic switching systems were developed using the principles established in the trail blazing AT&T No.1 ESS. Figure 1 is a chart of the principal electronic switching developments started prior to 1973. Most of those that were placed in production, as indicated by the cross-hatched lines, are covered in Part V.

Briefly restated these systems were the GTE EAX series, the Canadian (Northern Electric) SP1 developments, the Japanese D10, D20, ...) series, the ITT Metaconta series, the Ericsson AKE, ARE and early AXE systems and the Philips PRX. The German (Siemens) EWS system was a little late into the market and therefore its life was cut short by the move toward time-division digital switching. In addition there were the non-SPC systems such as the TXE2 system in the UK starting in 1966.

These systems were developed in the mid 1960s and early 1970s. Although each chose a different device for the space-division switching network, they all adopted the principle of stored-program control. This is the most convincing justification for the claim that the real invention in the use of electronics in switching was not this hardware technology alone, but the application of stored-program control which opened up to switch the new dimension of software.

Initially the cost of the new technology was high. Furthermore by this time there was growing evidence that the cost of developing these SPC switching systems was going to be much greater than for electromechanical systems. This

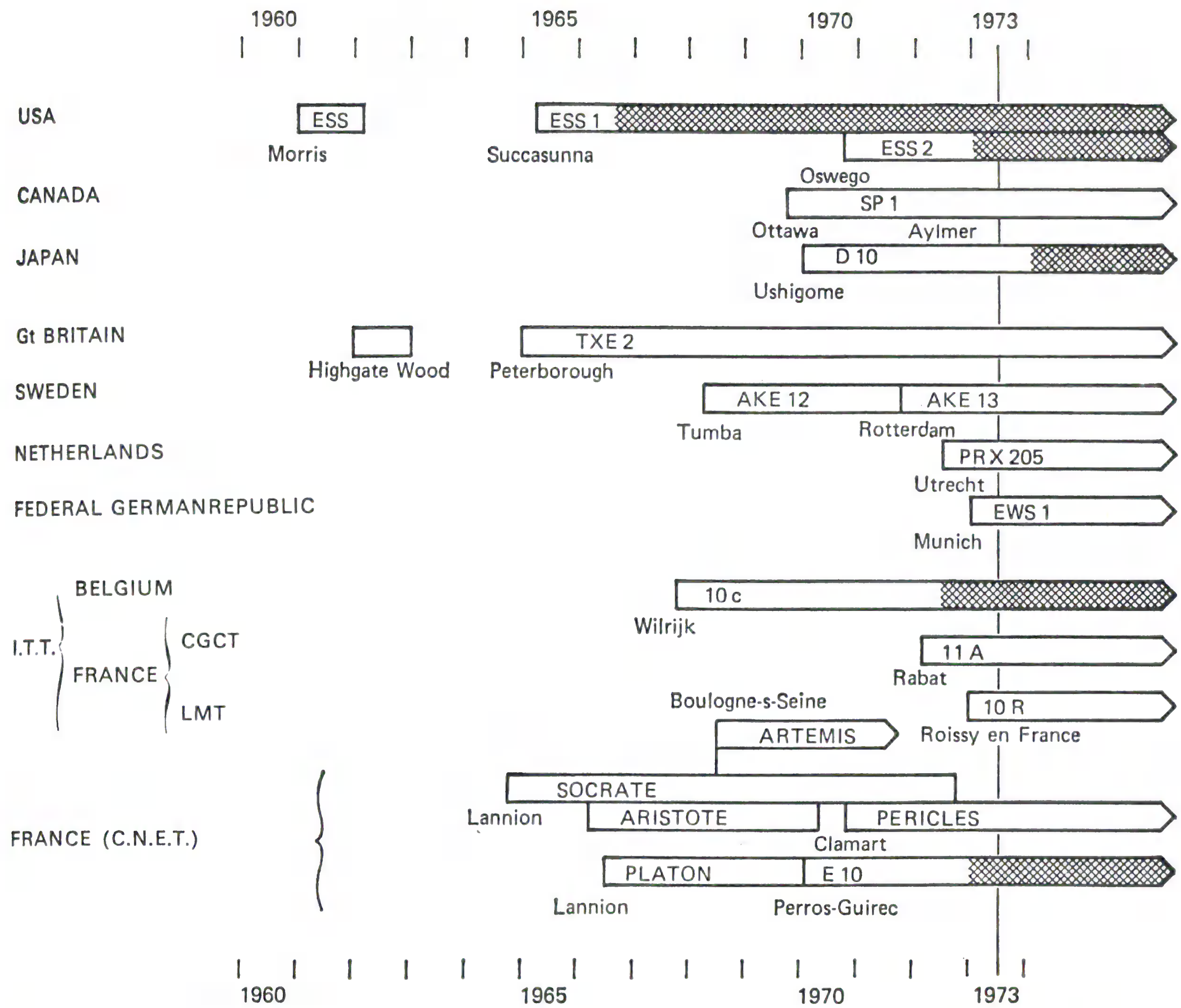

Fig. 1. Dates of appearance of principal electronic switching systems. The shaded strips show stored program systems in service for more than 10 000 lines. The date taken as the starting date is that on which the prototype exchange whose location is shown was put into actual service. The design of the system usually pre-dates this by at least 3 to 4 years.

was due in large measure to the cost of initial and continuing software development.

It took time for switching to be pointed in the SPC direction. Development engineers, administrations, and managers had to be convinced that this was the consensus for the future direction of electronic switching. They were skeptical about the reliability of electronics used in systems that required continuous service for tens of years.

The economic studies now contained many new elements. For example, no longer was a first cost comparison of electronic offices versus electromechanical ones sufficient. The reductions in the cost of maintenance due to possible greater component reliability and the automatic trouble detection, location, and centralization had to be considered. SPC-electronic switching opened the door to many new revenue producing services and this economic factor had to be taken into account. All these factors took time for resolution that ultimately favored proceeding with the development and deployment of electronic switching systems.

There were administrations at both extremes of the SPC space-division trend. For example, the French administration opted for an all out effort to introduce the integration of time-division digital transmission and switching, leading

the world into the next stage of electronic switching development (see Chapter V-8). On the other hand, the British Post Office having been burned earlier with their entry into time-division switching with Highgate Wood (see Chapter II-5) retreated to non-SPC reed space-division systems (see Chapter V-6).

3. Basic architecture [2]

3.1. Switching Networks

Unlike their electromechanical predecessors the first generation space-division electronic systems tended towards simplifying and standardizing on subsystems or "building blocks" of the system. For common control electromechanical systems, large numbers of unique purpose wires connected the blocks. The fewer blocks of these first electronic systems were interconnected by many fewer wires and most were readily identifiable. Wires, or "leads", were given names such as address, read, write, input word, output word, etc.

The multistage space-division switching networks were shown as a single block and controlled as a single network control subsystem. A common arrangement was for lines to appear on one side of the network and trunks circuit on the other. In addition to trunk circuits, there were a group of "service" circuits used to provide tones, to give announcements, and for other call service functions.

Rather than develop new technology for electronic switching, many designers simply confined themselves to transposing the prevailing electromechanical devices for the switching networks for use with the more challenging electronic controls. It was soon found that excessive buffering was required between the higher speed electronic controls and the existing space-division network devices that were orders of magnitude slower.

For this reason several manufacturers developed higher speed coordinate-matrix devices. Most were smaller than existing crossbar switches, therefore they were called "mini-crossbar". Some mini-crossbar switches were with mechanical or magnetic latching such as the ITT "metabar" or "multi-selecteur" and Japan's NTT crossbar switch. AT & T and Northern Electric made smaller crossbar switches. Ericsson's entry was a unique but expensive switch with extensive selection capability, known as the "code bar" switch.

But to attain greater network speed and to reduce manufacturing costs, individual crosspoint relay devices were developed for automated production. From the manufacturers indicated below, these included:

1) AT & T (Western Electric) – the ferreed and, later, the remreed
2) Siemens, the ESK strip of 5 relay crosspoints and the steel gas-sealed relays
3) Ericsson, GTE, ITT, Philips, and Plessey, sealed contact relays
4) Japan (later) – each manufacturer with a different ferreed-like device for export systems, and a small remreed device for the NTT systems.
5) GTE, later, the magnetic latching "correed".

With the use of so many electromechanical devices in the space-division switching network of "electronic" switching systems of this generation, there was much discussion as to whether such an adjective was appropriate. Engineering purists refused to call systems employing such devices "electronic" switching systems; instead they called them "quasi-electronic" or "semi-electronic". They considered only Highgate Wood and other time-division experiments as the only true "electronic" systems. However there was some change in attitude because most manufacturers no longer identified their systems by the type of device used in the switching network as was the case for the electromechanical switching era (step-by-step, panel, rotary, crossbar, etc.). Even AT & T's famous annual publication "The World's Telephone" succumbed by designating as "electronic switching system" – "any switching system (with a) control using electronic devices to perform logic".

3.2. Control

For the control portion of the system many approaches, with electronic logic taking the place

of relay logic, were tried. These approaches included electronic registers, register-senders or "multi-enrègistreurs". Other systems used electronic logic circuits in cooperation with tables in memory of "macro" or broad instructions, e.g. to deal with the request for a network connection. But by far the control technique adopted by most designers was store program control (SPC).

The architecture of all space-division SPC systems was essentially the same. Besides the single switching network control there was a single active SPC processor. There were groups of inputs and outputs from this processor to the lines and trunks.

Information to the processor, such as call originations and input address and supervisory signaling from the lines, trunks, and service circuits in the system periphery were generally assimilated by the central control by the so-called process of "scanning". Scanning implies periodically examining each input at a controlled rate. However, the scanning subsystems were also used for looking at specific inputs, as when looking for dial pulses. This was known as "directed" scanning. Some scanners were known as "testers".

For control signals leaving the central processor at high speed, electronic logic trees were used. These were known variously by terms such as "signal distributors" or "drivers". They delivered signals to the line, trunk, and service circuits and sometimes for the switching network control. In some systems separate output buses were to pass addresses to the switching network control from the processor.

The most prominent problems encountered as these first generation switching systems were introduced into the telephone networks was that of central processor capacity. While this involves both hardware and software, the "quick fixes" solution was proposed in many cases by the less burdened hardware designers. A common step towards the next SPC system generation was to provide "autonomous scanners" and so-called "signal processors" to serve the signals from the many thousands of system line, trunk, and service circuit inputs. This reduced that amount of effort required by the central processor for these repetitive operations so that they could focus on the less repetitive call processing actions.

4. Gaining experience

Systems described in Part V were the first electronic switching systems placed into production. When it came to commercialization much was learned first-hand by each entrant into the market. The designers learned of the difficulty of estimating real-time usage in predicting call attempt capacity. They also learned of the high cost of developing software, including the extensive tools required for its development. The manufacturers learned how to handle the large number of electronic components required to be placed on printed wiring boards before the advent of integrated circuits and the need for automated production and quality control. The administrations had to learn a whole new philosophy with regard to the craft training, and the speed of response when repair was needed since only duplex redundancy was provided. Finally, the systems proved to be much more reliable than had been expected. As a result craft people frequently forgot their skills for which they were trained when their skills were most needed!..

In the late 1950s and 1960s the flexibility of SPC was heralded as the greatest achievement of electronic switching as indeed it has proven to be. But to achieve these advantages required a whole new approach to the development of systems. The emergence of software as the basic ingredient in the design and development of switching system emerged as the signpost for future generations. As microprocessors and more powerful processor architectures entered the technology in the early 1970s, the software issue could not be avoided, much to the chagrin of some of the old-time telephone experts who wished for the good old days when systems consisted of only hardware.

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CHAPTER VI-2

THE SUCCESS OF THE SPC CONCEPT FOR THE DESIGN OF SWITCHING EXCHANGES. A CHRONOLOGY AS TRACED BY SUCCESSIVE ISSs

1. The upsurge in publishing

1.1. Prior to the advent of electronic switching, comparatively little was published on the architecture or development of switching systems. There was also very little interchange of technical information among administrations and between manufacturers. In the latter case each company in the field had a long history of proprietary developments which they pursued not only with their national administrations but also in competitive markets where there were no such technical developments or established companies. Export sales were generally made to colonies or dominions with established political relationships. It was only by this process that some technical knowledge was transferred and there was little incentive for its interchange with other foreign countries.

For electromechanical switching systems one was fortunate to find a single technical paper describing a new system that may have taken years to develop. Frequently such papers were found in so-called "house organs", publications circulated only within an organization. There was little interest in exchanging technical information on telephone switching between engineers in this or allied areas of electrical engineering.

Knowledge of switching systems in general was passed between generations by on-the-job training, and even then there was little acknowledgement of the relationship between designs of different systems. In-house training was generally intended for engineers and craftsmen responsible for the maintenance and growth of the telephone plant.

The subject of switching principles was not exploited. Few schools taught about switching, and where there were courses they were confined to describing specific systems. In Europe, however, a few institutes of higher learning did attempt to impart some knowledge about the systems then in use, particularly those used in their own countries.

As indicated in Chapter II-3, people with more formal education were attracted to the possibilities of electronic switching after World War II. They came from fields of scientific research where the "publish or perish" doctrine applies, and were therefore more inclined to describe their work to others who might be interested. Furthermore, much of the technology and many of the system concepts that were beginning to be explored for use in switching were of potential interest to those working in other areas such as computers.

It was therefore appropriate that wider dissemination of information about switching should occur. Most organizations looked upon this work as research and were not at that time concerned with possible competitive aspects. Already from the time of electromechanical switching technology, manufacturers had developed among themselves a network of patent licensing agreements that permitted the spread of unique technologies such as crossbar switches.

1.2. In the few organisations concerned with international telecommunications, such as the (pre-1956) CCIF within ITU, switching considerations and the signaling required for the automation of national traffic were considered to be

strictly national matters having no impact on international links and were completely excluded from deliberations until 1960 (see Chapter X-1).

After 1960 and the creation in 1956 of the CCITT to replace both the former CCIF (telephone) and CCIT (telegraph), the situation changed progressively. The spread of international dialing had a deep influence on the exchange of information on national switching systems. For international signaling, experts had to have a perfect knowledge of what were some very specific features of switching and signaling systems in a partner country. CCITT and its Study Group XI received an ever larger attendance and its field of activities – on par with the level of investment in the switching sector by telecommunication agencies – expanded by 1980 to account for almost one-third of all CCITT activities and studies.

In 1960 the IInd CCITT Plenary Assembly (New Delhi) decided, in a spirit of technical cooperation, to prepare what was to become the first CCITT "Handbook", entitled "National automatic networks". This volume, published in 1964, was to provide guidance "in the comprehension and analysis of the problems associated with the development of national telephone switching networks and the specification and selection of suitable switching systems for such networks". A corpus of sound standard practices was thus born. The book was widely circulated. Besides its publication in the three official languages of the ITU (English, French and Spanish), it was translated into many other languages: Chinese, German, Polish, etc.. Despite the evolution of switching systems, most of the basic principles set forth in the Handbook [1)] have remained virtually unchanged since the time (1960–1964) when, it was written by a small group of experts under the chairmanship of R. Banks (Australia).

[1)] Especially its Part B, "Choice and Supply of Switching Equipment", with Chapters detailing what technical and operating data were to be supplied by the Telecommunication Enterprise and, conversely, what essential technical data were to be supplied by manufacturers.

In 1976 the VIth CCITT Plenary Assembly instructed one of its "specialized groups" (a "GAS" group in CCITT jargon, reflecting a French acronym) to draft a new Handbook to deal with economic and technical aspects of the choice of one of the new generation of switching systems, i.e. those of SPC architecture. Again, this Handbook, published in 1980, obtained wide success. A hundred or so experts had been active participants in its drafting under the chaimanship of L. Ackzell (Sweden) [1].

2. The rise of professionalism

Another reason for the lack of publications on electromechanical switching prior to the 1940s may have been the type of persons who were most knowledgeable on the subject. For the most part they were the inventors, e.g. Bell and Edison, and highly individualistic persons.

With the appearance of scientists and graduate engineers on the scene in the late 1940s, switching came into its own as a recognized and critical element in the field of telecommunications. Persons with the same or similar qualifications had already demonstrated in transmission the accomplishments and advantages that the application of more disciplined approaches could bring to their field.

Professional societies recognized this and appropriate committees were established. In the United States, the Switching Committee in the Communications Division of the American Institute of Electrical Engineers (AIEE – a founding partner in the IEEE)) was established in 1948 and a Transaction section began publication in 1950. Similar activities took place within the IEE in the UK, the SFER in France, the NTZ in West Germany, the ALTA in Italy, the IECE in Japan, etc.

At regular meetings of these professional societies, sessions of talks and published papers were organized to cover current switching topics. Initially many of these dealt with the latest and final round of post World War II electromechanical switching and national and international network subscriber dialing. But it was not long

before papers began to appear on electronic switching topics. Among the earliest papers were those of Flowers (1950) [2].

Attendance at professional society meetings is not only to hear formal presentations of the latest in technology and system architecture: it also encourages the cross-fertilization of ideas and thought among participants. Since good ideas are accepted and poorer ones rejected by peers, there is a tendency for these meetings to result eventually in products that resemble one another. It appears that this was the case for many SPC systems brought on to the market in the 1960s after the successful introduction of AT & Ts No. 1 ESS (see Chapter V-2).

3. The impact of international symposia

3.1. The proud successes of AT & T in first the Morris system, introducing the concept of stored-program control, and then coupling the SPC concept with new magnetic device technology in the No. 101 and No. 1 ESSs, led AT & T (Western Electric) to hold professional symposia, with published notes, for patent licensees in 1957 and 1963.

The three day 1957 meeting was held at Whippany and Murray Hill from 4 to 6 March. It was preceded by a version given for the benefit of Bell System personnel on 18 to 20 February. The subject material included descriptions of the technology used in the Morris system, its various subsystems and the system application. There were representatives of 26 companies from five countries (interestingly no one from Japan was present since at that time there were no Japanese licensee companies). While there are no formal papers describing these symposia, the conclusion of a note prepared by Jouty for the French administration in 1961 (Box A) reflects the general tone among those who attended.

As part of their regular General Fall meetings, an AIEE session was also held in Morris on 15 October 1960.

3.2. In conjunction with the IEE of the UK, the British Post Office (BPO) held a general "Conference on Electronic Telephone Exchanges" in London on 22 and 23 November 1960. Obviously, the motivation for this conference was for the BPO and JERC (see Chapter II-5) to give their peers in the world of electronic switching their views of the future in this field through a detailed description and a visit to the Highgate Wood time-division exchange using Pulse Amplitude Modulation (PAM) pulses.

Box A

A French 1961 Report on the Morris exchange (translation of extracts from its conclusions)

We saw the prototype of an electronic switching system in operation at the Morris exchange. We were struck by the magnitude of the problem involved and the financial and resource means employed to solve it.

The Morris exchange undoubtedly offers a valid solution, at least from the operational point of view, although the gigantic effort which has produced that significant result will have to be sustained for several years to come and heavy expenditure will be needed on improvements before the system can be considered better than the crossbar, even taking into account the extra facilities it has to offer, at a certain cost, to American users. It is by no way sure that French users would be prepared to pay for facilities of this type. We are led to believe that only an organization as big and wealthy as the Bell System can afford to contemplate such experiments.

While considering that electronic switching is almost certainly the right solution for the future and that any country wishing to keep up to date should definitely carry on research in this field with a resonable outlay of funds, we believe that, at the time being, the French Administration, for which the crossbar fortunately still offers a cheap way of solving all current operational problems, probably has nothing to gain by rushing headlong into such a venture.

3.3. By 1963 AT&T was ready to introduce its new generation of switching system accomplishments. It chose the same route for telling the world, i.e. a symposium held on its premises. from 21 to 24 January, this time at Holmdel, New Jersey. Again, there were no formal discussion but Flowers gave a memorable speech at the close of the symposium saying in effect that only a large effort of the type discovered at the symposium was likely to produce an economical system since component devices then available in the marketplace were too expensive and their reliability uncertain. However, in general the SPC concept was widely accepted at the time and did not bring forth much discussion.

3.4. To demonstrate early progress in electronic switching in general and with particular emphasis on the newly created stored-program control for switching systems, a series of international meetings had been held since 1960 every two or three years in different countries, most of them sponsored by the local electrical engineering professional societies. Since 1972 they have been known as the International Switching Symposia (ISS).

The Proceedings of the ISS meetings have been one of the most useful sources of technical information on electronic switching systems [2]. Including the meeting held in Phoenix, Arizona, USA, in March 1987, there have been twelve ISS meetings with 1484 papers published (not all were presented). The content of these papers represents a spectrum of the progress made in electronic switching from its early days of experimentation through to the full manufacture and deployment of several generations of systems. Excellent summaries of these meetings have been provided by P. Lucas and P. Collet of CNET in France and some others (see Bibliography [3 to 9]).

[2] An archive of the ISS Records is maintained at most of the Engineering Societies Libraries, e.g. at IEEE Headquarters, 347 East 47th Street, New York, NY 10017 USA.

Table I [8]
Origin of papers accepted by the Phoenix ISS 1987

	A	B	Total
USA	35	6	41
Japan	21	2	23
France	20	3	23
West Germany	20	3	23
Canada	17	2	19
Italy	12	1	13
United Kingdom	7	0	7
Sweden	5	0	5
Belgium	3	0	3
Netherlands	2	0	2
Switzerland	2	0	2
Australia	2	0	2
Spain	1	1	2
Brazil	1	0	1
Denmark	1	0	1
Finland	1	0	1
Norway	1	0	1
China	0	1	1
Taiwan	0	1	1
Total	151	20	171

Column A = selected for presentation; column B = selected for publication only.

Also of interest is the large number of countries that contribute papers to the ISSs. Table I lists the 19 countries from which contributions were accepted for the Phoenix ISS 1987. More than three times this number of papers were submitted for consideration by the national organizing (USA) and international advisory committees.

3.5. The following is a list of the ISS meetings with a general comment on the state of the art that seemed to be the consensus of those who attended.

1957 – Murray Hill and Whippany, New Jersey, USA (Bell Telephone Laboratories) – Introduction to the first successful electronic switching system employing stored-program control and electronic speech paths.

1960 – London, England – Introduction to progress in time-division techniques, including detailed disclosure of the British Post Office's analog time-division system at Highgate Wood.

First SPC processors and experiences with Morris ECO were also covered.

1963 – Holmdel, New Jersey, USA (Bell Telephone Laboratories) – Descriptions of the first production of electronic switching systems for central office (No. 1 ESS) and PBX (No. 101 ESS) applications.

1966 – Paris, France – Presentations were made on a wide variety of space- and time-division system experiments as well as space-division systems in production.

First papers on software problems: they were the source for prompting international studies of software for SPC systems by CCITT (from 1968 Mar del Plata, Argentina, Plenary Assembly) [3].

1969 – London, England – A continuation of the type of material covered in 1966 with more emphasis on systems in production.

1972 – Cambridge, Massachusetts, USA – The first digital time-division systems then under development emphasized an impending change from space- to time-division, and the initial appearance of digital technology in switching networks for speech paths.

Until 1972 there had been no formal method of determining the location and sponsorship of succeeding switching symposia. By 1972 many new systems from many countries were then coming into production and deployment. It was no longer feasible to concentrate on one country at a time as being recognized for the current foremost developments in electronic switching. As a result there began to arise the possibility of conflicting meetings in different countries at the same time. At the 1972 meeting the first International "Ad Hoc Committee" for ISSs was formed with the objective of ensuring the orderly continuity of future ISS meeting locations and procedures.

[3] While there are sessions on switching system software at each ISS, a separate series of professional conferences on Software Engineering for Telecommunication Switching were established, starting in 1973 (with later: 1978 (Helsinki), 1980 (London), 1986 (Eindhoven)) (see Chapter VII-1).

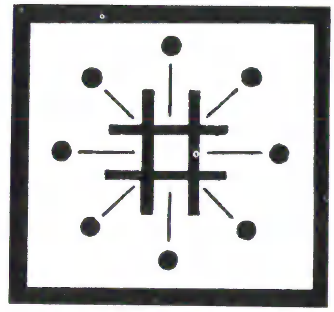

Fig. 1. The ISS symbol

At the Boston 1972 ISS, a badge/symbol for the ISS meetings (fig. 1), devised by Amos Joel, was first displayed. From then on this symbol was used extensively including in ceremonies before the attendees at an ISS closure session, when each country responsible for the ISS venue was proudly handing over "the ISS flag" to the team responsible for the next ISS.

1974 – Munich. West Germany – Many in-production space-division systems were described. The needs for modular architecture of the SPC systems to take into account fast developments in their hardware components were put into evidence.

1976 – Kyoto, Japan – Distributed control became a new attribute to be exploited in the architecture of switching systems.

1979 – Paris, France – Digital time-division switching was now the leading technology for switching networks of SPC systems. Many papers were devoted to remote switching.

1981 – Montreal, Canada – Second generation time-division digital switches were heralded.

1984 – Florence, Italy – The principal theme was how to utilize the digital time-division technology to encompass data as well as voice communications and to anticipate the emerging need for Integrated Services Digital Networks (ISDN).

1987 – Phoenix, Arizona, USA – In-production systems and trials of systems arranged to provide ISDN were described and demonstrated. Some early work on broadband and other speech path architectures began to appear.

Fig. 2 summarizes for these meetings the location, attendance and papers published.

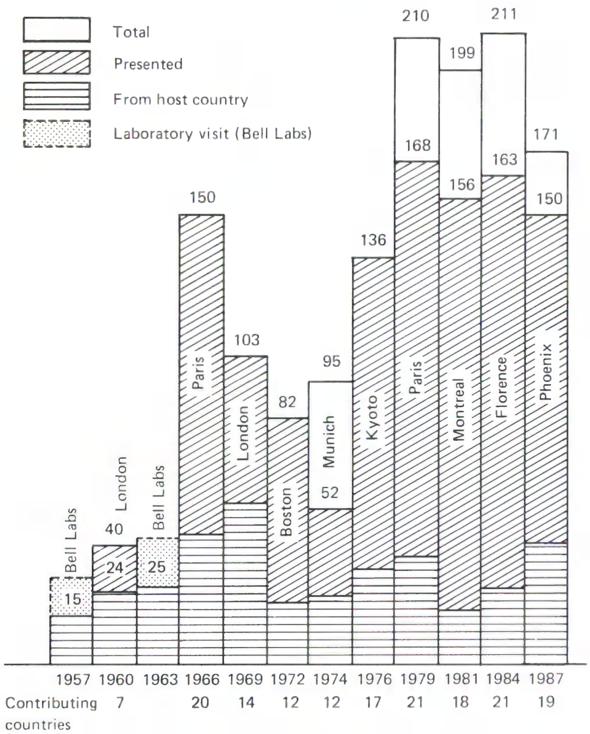

Fig. 2. - Locations, attendances and number of papers published for the 1957 to 1987 ISSs. (from [8])

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Part VII

Software for SPC systems

CHAPTER VII-1

SOFTWARE FOR SPC SYSTEMS

1. General considerations

1.1. Over the years, software costs for SPC systems have not followed, and indeed they are still far from following the sharply downward curve of hardware costs, particularly for electronic components.

In SPC switching, as in every intensive computer application, the software complexity has steadily increased. SPC software is always intricated and, in switching systems, software defects are no less important than hardware breakdowns and are harder to detect. Program design errors very often show up only in remote secondary effects that are almost unforeseeable at the design stage. The production of perfectly reliable SPC software is therefore particularly costly and time consuming.

Maintenance and updating of SPC software throughout the life-time of a switching system is also a hard and exacting task and therefore no less costly. The extent of the problem became apparent as the first generation of SPC switching systems reached maturity. The difficulties are compounded when the switching system is designed for use in many countries, each with its own network characteristics and peculiar constraints.

1.2. To the switching equipment developer and manufacturer, the design, production and debugging of software now account by far for the largest slice of the development budget of any system. In the case not of a system but of a family of systems intended to cover the entire range of exchanges, from low-capacity local to large trunk transit exchanges, the initial development of software programs now has to be counted in thousands of programmer-years with continuing expenditure of effort for at least two system generations beyond.

Consequently, software problems are, if not the terror (and they sometimes have been), at least the source of many headaches of switching industry managers.

2. Specificity of switching software [1–5]

The important place that software production occupies in the switching industry is due to its particularly specific nature. There are five basic reasons for this:

- the complexity of the software;
- its consequent size;
- the long working life required of it;
- the need for real-time operation;
- the stringent reliability and availability required.

Among these factors we may note in particular the long working life, which is quite unique compared with that of software for other large systems. For that reason and to spread their high investment in software development over succeeding system generations, most switching system manufacturers now also add a sixth attribute to the list, "portability of the software", i.e. the ability to adapt it to the successive generations.

3. Complexity of switching systems and their software

Switching software complexity is a reflection of switching systems complexity. For the layperson and for engineers active in other fields, we briefly mention here the multiplicity of factors leading to this complexity:

- the multiplicity of units connected to an exchange and to be served, each unit having multiple characteristics of its own. There are, first of all, the subscriber lines, numbered in tens of thousands. Each of these subscribers, depending on his access conditions, may have dozens of assignable attributes reflecting his service needs. Then there are the circuits, numbered in hundreds, for which there may be a great variety of signaling modes;
- the multiplicity of hardware units within an exchange and, consequently, the multiplicity of their interfaces;
- the multiplicity of requirements of each telecommunication operating agency (Administration or company) with regard to the administration of its exchanges, the collection of charging information, the maintenance, the traffic routing and network management procedures, and, on top of this, the multiplicity of such operating agencies.

This complexity of systems' software due to multiplicity of factors is increased by the extreme fragmentation of the operations involved in execution of the programs, together with the fact that all these operations are closely interdependent.

4. Software dimensions

4.1. With time, as SPC system software became more and more complex, it became larger and larger.

SPC system softwares run into hundreds of thousands of instructions. The actual number depends on several factors such as the complexity of the requirements [1)], the maximum size of the system and the traffic volume to be handled by an exchange. Usually, the volume of software in a switching system is expressed in number of lines of instructions. Sometimes, different units are used: – program words, or bytes (i.e. octets). (Without a common unit, it is difficult to compare volumes of SPC software.)

A distinction is also to be made between what makes up the software used in a specific SPC office and what constitutes the software of a particular switching system and, a fortiori, of a family of such systems. The estimate for a family of systems is generally over a million instruction lines. Examples of systems with four or five million instruction lines in their software library are not uncommon.

(Such estimates do not claim to be anything more than offering a very approximate order of magnitude, particularly since the number of instruction lines is constantly growing. As an example, the software of ATT ESS No. 4 system (handling long-distance calls) was reported to have 1.1 million instruction words when first placed in service in 1976. By 1980, it had 2.2 million instruction words [8].)

For large systems and families of switching systems, there is also a large body of software required for the general-purpose computers used in the development process to simulate, debug, load, keep track of, and assemble ("link") the sections of code as they are written. The size of this software is larger than the software that eventually finds its way in each office. Keeping track of the software installed in each office of a popular switching system is also an important function of the manufacturer and requires considerable computer and data base facilities. Largely as a result of experience with general-purpose computers for these tasks, the designers of more recent generations of switching systems have turned to the use of the form of "operating systems" [9].

1) General purpose computers have now been called upon just to keep track of the hundreds of system requirements. For modern public central offices for applications in a highly commercialized society, there are multi-volume sets of requirements to be catalogued and strictly defined, a fact which is understood and appreciated by very few, [6].

For the switching equipment manufacturer, obviously it is the whole set of software for his family (or families) of systems which will determine how software is to be produced and how many staff are to be employed in programming them.

4.2. As a typical example of the complexity and size of a telephone software, we may cite a paper issued at ISS 1984 in Florence [10]. This paper is not actually concerned with the software for a family of public exchanges switching systems, but solely with a PABX system. This is a digital multi-service system intended both to provide telephone service and to process data and texts. (Given the difference of scale between a PABX and a public switching system, these points are highly significant.) For this PABX:

"– Some hundred people were involved in the development of the software, in different places and in different countries;
- A development period of several years had to be reckoned with;
- The software was of considerable size: about 1 500 source modules with about 800 000 source lines and more than 10 MByte of program code;
- The main programming language used was CHILL, but there were also parts coded in Assembler or in PL/M."

4.3. The technical literature on electronic switching is not very generous with information on programmers' productivity, which is sometimes expressed in terms of the "time spent by a programmer per instruction line". The productivity depends essentially on the way software is produced, i.e. the organization of the software units and the software environment which provides the programmers, for better or worse, with the tools they need.

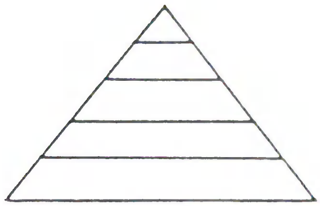
Despite the very natural reservations by management about publishing detailed information on its firm's industrial efficiency (one of the key factors in its economic success), the technical literature provides some limited information on the average programmers' productivity. "An average programmer time to obtain a useful instruction line would be ranging about 100 minutes". This would cover not only the coding time proper, but also the time spent on specifications, design, integration, editing and "debugging" of program texts. (For justification of this figure, see in [11] a detailed analysis of programmer productivity in an efficient firm in 1979). (Also included should be the time spent in analyzing and rewriting programs produced in high level languages that need fine tuning to reduce real-time requirements.)

The somewhat arbitrary nature of this type of average, and even the mere idea of quoting a figure of such a type, have sometimes been denigrated as belonging to the realm of pure "myth" [12]. The simple fact that there are very appreciable differences in the nature and complexity of different software subprograms, and also differences resulting from the languages used for programming, is an initial argument against the validity of quoting a figure of this kind. A second argument is that it is not enough to employ more programmers in order to get switching software prepared more quickly. Whatever the degree of modularity of the software, the operations involved in preparing it have to be done more or less in sequence.

4.4. However that may be, considering a programmer's productivity at 2,000 hours a year, it is possible to arrive at a rough estimate of the number of programmer-years involved in preparing software for a switching system. This figure runs into thousands. Therefore, it is easy to see what a large number of highly specialized staff a switching equipment manufacturer has to employ for his system software.

The figure for the battalions of programmers engaged in producing switching software, with all the problems related to work-coordination, alone is enough to show that software has become a decisive element in the production cost of a switching system. Since the beginning of the 1980s the mode of production of such software has accordingly undergone a very marked development involving all the principles of software engineering (see Chapter III-4, under 3.3), the applications of which obviously concern many other branches than the switching industry.

The management of teams of programmers and coordination with other system designers has



Superlarge	(Over 512K)
Large	(64K to 512K)
Medium	(16K to 64K)
Low-medium	(2K to 16K)
Small	(Less than 2K)

Fig. 1. Programs classified by size (in K instruction lines) from [7].

been recognized as the most important aspect of new switching systems development [2,13]. Management teams, as well as the programmers, need to have considerable applicable experience. The more experience, the higher the quality of the final product and the less time needed to debug, making the entire process more efficient.

4.5. Together with the computer and aerospace industries, the switching industry is one of the leading users of very large programs.

In [7, pp. 125–161], Capers Jones reviewed world production of programs in 1976. He ranked them by size n five different categories, in the form of a pyramid, the levels of which represented stages in a binary evaluation scale, the unit adopted being 1,000 (or K) instruction lines (Fig. 1). Capers Jones estimated in his 1976 survey that less than 1% of programs were in the top category of his pyramid (programs with more than 512K lines). They undoubtedly included programs for SPC switching systems.

5. Life of switching software

5.1. It has been asserted that, in any family of switching systems, the software should have a life of up to 40 years [14]. This figure is based on experience acquired with electromechanical systems of which some exchanges have lasted even longer. The increasingly rapid advances in technology, however, do not necessarily mean that electronic exchanges can be expected to last as long; indeed, they are likely to become obsolescent more quickly, but we can safely say that software for switching systems now being produced will still be in use in exchanges at the start of the 21st century.

During the life of a switching system, its software is continually being developed and expanded due to:
- new services which the system has to provide;
- new requirements that may emerge in the administration and maintenance of the system and, more generally, in network management;
- applications which will differ from country to country and even with the site on which an exchange is installed;
- technological enhancements leading to the replacement of system hardware components by others with higher performance or lower cost.

5.2. The question of maintaining software throughout its foreseeable life ("Programming-Life-Cycle Analysis") is by no means peculiar to the switching industry. It is widely discussed at meetings of computer experts in all industries using software on a large scale. At the beginning of the 1980s, it was concluded that the importance of software maintenance had been underestimated [2] [4, p. 121] and it was noted that "of course, for systems with a life of 15 years, there has not been enough time to carry out many studies".

The life expectancy of SPC system software is quite exceptional compared with that of software for other major systems where it is not much more than 10 or, at the most, 15 years.

2) Despite a review of published texts which showed that in 1981 more than 50 books devoted entire chapters to the subject [4, p. 122].

6. Demands of real-time operation

Severe constraints are imposed on switching software owing to the fact that a switching system has to operate in real time.

An inherent difference exists between computers for general use and those intended to control an SPC switching system: because of that difference the latter are specifically named "processors". Their difference lies primarily in the software used. The architecture of an SPC system is conceived to meet the requirements of real-time operation and its software is its faithful reflection.

Among the demands made of SPC software, the most severe constraints have to do with the many different phases of call processing or with signal processing. In such cases, the reaction times imposed may be less than 10 milliseconds.

Switching software has to deal not with just an isolated call but with a great many calls simultaneously. Calls occur in the greatest disorder, traffic is random and extremely erratic. It is characterized by call bursts that happen simultaneously. A typical example is given in GRINSEC [3, p. 314]: in a local exchange with 30,000 lines, there may be 3,000 telephone calls in the speech phase at any given instant, plus 500 calls being established or released.

The call handling capacity of an exchange is generally defined in terms of the number of Busy-Hour Call Attempts ("BHCA"s). (The layperson will note that there are more than twice as many call attempts as calls giving rise to a conversation, owing to attempts which encounter the engaged tone or no-reply by the called subscriber and to cases where the caller hangs up before he has finished dialing.)

7. Software reliability [15]

7.1. SPC system software is an intangible and invisible concept, with an extremely complex structure. Specifying reliability criteria or standards for such software is not easy. It is even more difficult when contractual guarantees between the manufacturer of an SPC system and the entity (administration or private operating agency) purchasing its exchanges have to be defined.

The problem of software quality, of course, is not specific to switching. It is also a vital problem for all computer users and manufacturers. Attempts have been made, for instance in the United States by the IEEE, to draw up quality standards, but these are very difficult to establish. To identify appropriate means of satisfying these quality conditions, methods have been developed which include the "software quality insurance" (SQI) method designed for the Department of Defense (DoD) in the United States. Bell Communications Research (Bellcore) also provides guidelines on software quality requirements to vendors offering SPC central offices to Bell Operating Companies [16].

Since the mid-1970s, software reliability has become a discipline in its own right in which a great deal of work has been done, and the interest evoked goes far beyond the circle of experts in the subject. Science fiction authors have made it a theme for paperbacks, with fantastic stories of espionage and cunning piracy of software handed over to foreign powers. In view of the public's interest in these best-sellers, journalists in turn have not missed the opportunity to expand on the subject, devoting whole newspaper columns to software, its problems and intricacies.

Reverting to more serious matters and to switching software, it is worth mentioning that there is no international telecommunications conference where software reliability is not an important item. This is particularly true of the following conferences of world-wide reputation:

- the ISS (International Switching Symposium) where whole sessions are devoted to the subject (e.g. session 14C of ISS 84 in Florence);
- the International Teletraffic Congresses (ITC), see for example reference [17] submitted to ITC-10, Montreal, 1983;
- the International Communication Conferences (ICC) organized by IEEE [3)].

And finally, of course, high priority is given to software reliability in the even more specialized "Conferences on Software Engineering for Telecommunications" which meet every three years, since the first one in London (1973).

7.2. If we refer to various papers presented to ISS 1984 in Florence, the situation as regards switching software quality and reliability at this time may be broadly summarized as follows:

a) in the initial phase of a system's operation, it is possible to weed out more than 95% of software faults through normal testing and diagnosis procedures. Since in practice it is not possible to anticipate all potential combinations of software failure, breakdowns will inevitably occur, albeit rarely. Their preventive detection by using normal procedures is very difficult. Certain authors came to the conclusion that at present it is impossible to *design* a "zero error" program ("program testing only shows the presence of errors");
b) as software becomes more sophisticated, the cost of modifying it increases;
c) when a new switching system (and particularly the first exchange of a given type) is first brought into service in a country, the software often has to be modified to take into account constraints arising from the pre-existing status of the network. Some authors use the term "country adaptation" ("acclimatization") to cover all such modifications. Inevitably, certain software faults will not be detected until the system is brought into service. However, if the system is of sound design and has been thoroughly tested, most of these errors will not affect the continuity of the service provided.

8. Availability of switching software

8.1. The availability conditions of an SPC system

Another factor, just as important as real-time operating conditions, which distinguishes the "processors" of an SPC system from general-purpose computers is the service continuity required. This aspect, quite obvious for telecommunication engineers, is worth going into here for those not familiar with the problem.

Operation of a general-purpose computer may be stopped at certain times without any serious consequences. There might be regular interruptions for maintenance operations, or episodic interruptions for unexpected reasons, where the break in service has no other effect than delaying the execution of a program. Requirements are totally different in a telephone exchange. Nowadays, the widespread telephone use has made subscribers and the public extremely demanding. "A complete failure of a local exchange for even a period of 15 minutes is an event so rare that generally it is reported in newspapers" [19]. Availability standards laid down for exchanges are thus extremely severe. The standard applied for Bell System Companies' central offices, for instance, allows a maximum of two hours' break in the operation of an exchange during 40 years of service. This standard has now been introduced in the state-of-the-art specifications published in the CCITT Handbook on SPC exchanges.

There is nothing more subtle than the probability calculations by which the related standards are determined. These calculations, which take into account all parameters involved, each with its own weighting, identify the constraints to be respected for each of the parameters in order to attain the overall availability objective set for an exchange, as, even more important, for availability of service, including trunk and international services. The following figures are CCITT standards (provisional figures) for the availability of an SPC system and of the constituent parts affecting the availability of service provided to subscribers. They are extracted from the CCITT Handbook "Economic and Technical Aspects of the Choice of Telephone Switching Systems" [20, p. 185], published in 1981):

CCITT Availability Standards

Unavailability:

– of the entire system	$< 1.5 \times 10^{-5}$
– of a subscriber line	$< 10^{-4}$
– of an interexchange circuit	$< 10^{-4}$
– for emergency calls	$< 1.5 \times 10^{-5}$

[3)] e.g., at the ICC in Amsterdam, 1984, no less than seven papers [18] described how to obtain the desired level of software reliability and how various programming languages could be used for the purpose, special emphasis being placed on the CCITT languages CHILL and SDL.

– for basic telephone service	$< 10^{-4}$
– for supplementary telephone services	$< 10^{-3}$
– for charging	$< 10^{-4}$
– for traffic measurement	$< 10^{-3}$
– for administrative operations	$< 10^{-2}$

To satisfy such rigorous requirements, a whole series of design arrangements are necessary. These concern first of all the system architecture. Provision is made in this architecture for:

– replication of a number of units;
– fault detection;
– reconfiguring the remaining working units after a unit failure;
– fault diagnosis;
– a scale of priorities for fault clearance, classified according to the seriousness of the fault.

No less than for system hardware, the reliability of the software is a decisive factor in ensuring continuous operation. The programmed processor technology provides adequate tools for supervision of service continuity. Besides monitoring by built-in means (such as parity bit supervision, automatic check summing, time supervision of basic operations), overall operation is audited by programs that exercise the processors and compare the obtained results with the expected results [20, p. 13].

Fault detection and diagnosis is performed in SPC systems and uses software techniques. Generally, more than half of the lines of code written for a central office switch are for these purposes.

8.2. Risks not to be underestimated

The experience acquired after 20 years of managing SPC exchanges provides ample proof that SPC systems and their software are capable of ensuring continuous operation of exchanges.

Nevertheless, the risk of serious breakdown in an SPC system should not be underestimated, even with the most reliable software and system. Indeed, the more reliable a system, the less those in charge of the equipment are familiar with the actions needed for restoration in case of a system crash: they are out of practice when confronted with such a major problem. For this reason, many administrations have found that maintenance personnel is more efficient and knowledged when they are able to exercise their skills for several offices simultaneously. This led to the development of centralized operation and maintenance centers (OMCs) where maintenance skills are better honed by being used more frequently.

A peculiarity of software faults is their unfortunate and annoying tendency to occur in the most critical situations, i.e. at peak traffic periods. These faults may then lead to a situation where the exchange is artificially over-congested. Even when all the in-built safety measures (duplication of control units) and precautions against traffic overload (restricted acceptance of new calls) were operational, such faults tend to be compounded precisely because of the congestion and may finally cause the collapse of the system.

Without equating in any way:

– the seriousness of a break in the operation of a telephone exchange, however large, and
– a major accident in the performance of a nuclear reactor of an electricity power station, like the one which some years ago hit the headlines throughout the world,we must, nevertheless, acknowledge the striking analogy between these two types of serious events insofar as:
– they are both extremely rare;
– human factors – the vigilance and professional skills of the staff in charge – are of overriding importance in coping with what is an extreme emergency.

8.3. Professional qualifications of staff responsible for SPC equipment

There is obviously a direct relation between the skills demanded of staff responsible for SPC equipment and the professional grade and level of remuneration given to such staff.

Especially for the benefit of the administrations in developing countries, it may be worth drawing attention to the interest shown in this subject in the seminars organized there by the ITU. When discussing modern switching systems, the lecturer had occasion to mention the considerable amount of investment required for a country's telephone exchanges. In order to give a clearer idea of the corresponding financial outlay, he compared it to the cost incurred by the country for its commercial airline's fleet of civil aircrafts. The point

of comparison was that, as a general rule, the cost of switching equipment in a country was now generally greater than that of civil transport aircrafts in the same country.

This comparison between civil aircraft and telephone exchanges led to further considerations concerning maintenance. We are all aware of the scrupulous care, quite understandable in view of the human safety factors involved, with which the aircraft of commercial airline companies are checked and maintained. A recurring concern of telecommunication authorities is the need for better maintenance of telecommunication equipment and particularly of exchanges. One of the basic issues in this respect is the technical skill of maintenance staff and, correlatively, their level of pay to correspond to their professional qualifications. One emerging conclusion for the developing countries was to undertake a proper study of the responsibilities and employment conditions of maintenance staff, especially at SPC exchange control, and to avoid remaining tied to traditional and hence outdated structures dating back to decades when the state of technology was not comparable to what it is today. For such a study, a comparison between the two already mentioned areas of activity – commercial aviation and telecommunications – could prove most useful, since it would throw light on activities in sectors governed by very different sets of administrative rules.

To conclude this digression, it appears that the main skills required of staff in charge of SPC equipment are very much determined by the exchange software, of which they must possess a very clear understanding. The maintenance staff must have an excellent knowledge of the system, including tools such as the "man-machine" language which is the principal means at their disposal for supervising, monitoring and controlling the equipment. They should also have been disciplined strictly to respect the instructions prescribed for dealing with serious breakdowns.

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CHAPTER VII-2

THE ORIGINS OF THE CCITT SOFTWARE LANGUAGES FOR SPC SWITCHING SYSTEMS

1. In the late 1960s, with the increasing use of SPC telephone switching, programming became an important part of telephone technology. SPC software systems were already large and complex and the use of proper programming tools became of great importance. The software for SPC systems had been discovered to be of a different nature from that used in many other applications: besides its size and complexity, it needed a specific reliability and to be extremely fault-tolerant in the presence of hardware faults and misoperation, while the long lifetime of 20 years or more for switching systems imposed the need for effective software management to cover the changes necessitated by new service requirements throughout its life [1].

2. The 1966 Paris ISS was marked by the appearance of the first lectures on software used for programming SPC telephone exchanges. It was the time when many special purpose languages were being created by various manufacturers of SPC switching systems.

A book by Hills and Kano [2], which came out in 1976 and was in its day a best-seller among switching engineers, takes fairly accurate stock of the 1960s developments in telecommunication languages by describing almost a dozen of those published and put into operation between 1970 and 1974. Three of them were British (UK Post Office and University of Essex), another three were American (two from Bell Laboratories and the third from General Telephone, i.e. GTE), and there was one from France (CNET), one from Japan (NTT), one from Sweden (Ellemtel) and yet another from the multinational ITT Group. The majority of those languages were PL/1 based. The authors also referred to the Pascal language (Wirth, 1971) as a likely candidate to provide the basis of a developed programming language for SPC systems.

In the course of informal talks during the Paris ISS the idea of promoting CCITT studies on this new subject of programming for SPC systems was launched by some of the ISS participants. The topic was very different from those traditionally covered by CCITT and there was some doubt as to whether the ruling authority of CCITT, i.e. its Plenary Assembly, would accept the task. The idea flowered, however, and at Mar del Plata (Argentine) the CCITT "Telephone Switching" Study Group (S.G. XI) was entrusted by the 1968 Plenary Assembly with a specific question on software for SPC systems. The question was formulated in the most broad and general terms.

3. Study Group XI scarcely knew what was expected of it when it took this new Question during the first of the statutory four-year periods before the 1972 Plenary Assembly. First, its regularly attending delegation of faithful experts had to make room for newcomers, experts in the new discipline of software. This took some time. It is thus hardly surprising if the 1968–1972 period was little more than one of exploration since the CCITT was venturing into virtually unknown waters. Nonetheless, three specific lines of thought eventually emerged as to what might be required in the form of CCITT Recommendations, i.e. the need to define the following three programming languages:

- a Specification and Description Language ("SDL"),

- a High Level Language for programming SPC systems (later known as "CHILL", the acronym of CCITT High Level Language),
- a Man-Machine Language ("MML").

The CCITT activities were aiming at obtaining one standard language for each of these three specific purposes. The standardization aspect was motivated by the fact that the telecommunication community is a very large one, distributed all over the world. Many users – present or future – of SPC switching systems, i.e. telephone administrations, obtain their equipment from different manufacturers. The benefits of standardization in these three software fields were to be subtantial for both users and manufacturers of switching equipment [1].

CCITT work on the three lines of study identified in 1972 was actively pursued in each of the working groups set up within Study Group XI and, within the space of four years, led to the formulation of CCITT Recommendations on the standardized form of the three languages mentioned above, now known as SDL, CHILL and MML.

The order in which the languages are enumerated is that in which they are listed in the "Z-series" [1] of CCITT Recommendations; indeed, that order is absolutely logical since, before a system can be programmed using CHILL, its specifications must be defined very accurately via SDL. The system itself must exist, at least on paper, before thought is given to how detailed instructions should be formulated for commanding and maintaining it by means of MML. In the same order, Chapters VII-3 to VII-5 below describe each of the languages in turn, together with their origins and subsequent deployment.

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[1] Each series of CCITT Recommendations is characterized by a key letter indicating the particular field of a Study Group. The Recommendations on programming languages were assigned to a new series separate from the "Q" series which covers Study Group XI's traditional field, i.e. telephone switching and signaling. This was the "Z" series, the letter being chosen so as to leave a number of letters towards the end of the coding system for possible future fields of CCITT activity. The choice of the letter Z was inspired by a weary joke (Z for "Zoftware"!) which may nonetheless have some mnemonic value.

After some hesitation at successive CCITT Plenary Assemblies, the differing nature of the Q and Z series of Recommendations gave rise to the creation in 1984 of a new Study Group – Study Group X – responsible for all studies relating to telecommunication software for both telephone switching and all other fields, including data transmission and processing, for, inter alia, the ISDN.

CHAPTER VII-3

THE CCITT "SPECIFICATION AND DESCRIPTION LANGUAGE" ("SDL")

1. The "raisons d'être" of SDL. Its origins and advantages

1.1. The "raisons d'être" of SDL. As we have seen in Chapter VII-1, the software of large switching systems is characterized by high complexity and dimension, parallel development and a long life-cycle with problems of updating and maintenance for many years [1].

From the late 1960s, the success of SPC systems pointed out the need for a standard development methodology covering all the design phases – from specification to test and release – if high productivity, high quality and a complete documentation of the release software were to be achieved.

One significant development of the early 1970s in SPC software technology was the international definition by the CCITT of a "Specification and Description Language" (SDL).

SDL is a formalized method of presentation of the functional specification – the required behaviour – and of the description of the internal logic processes necessary to implement the specification – the actual behaviour – in telecommunication systems [2].

SDL was first specified by the CCITT in 1976 [3] to provide a graphical means of specifying the behaviour of SPC switching systems. It was to be used both as a software development tool and as a high-level documentation technique. Based primarily on *state transition diagrams* [1], SDL combines traditional flowcharting features such as operational (tasks) and decisions with the concept of *signals*, allowing communication and synchronization between concurrently executing program units. Each SDL diagram is used to describe a single concurrent *process*.

In the early 1980s, besides the more commonly used graphical form (known as SDL/GR), an equivalent program-like form (known as SDL/PR) was also developed by the CCITT.

1.2. The advantages offered by SDL are several, for both the switching equipment manufacturer and the telephone "operator" (Administration or private operating agency) who is the user of the switching equipment:

a) For the equipment designer:
   - it is well suited to a top-down design technique,
   - it is oriented to demonstrate and solve problems related to process interactions in a switching system,
   - many automatic tools are available for storage, updating and logical verification of SDL specifications. The SDL diagrams are easily transformed in to Petri Networks, which allows for analysis and verification of concurrence and protocol aspects [4],
   - tools have been developed for translating SDL/GR specification into a SDL/PR form or into CHILL code, and vice-versa. For example [5], an SDL translator checks the syntax of specification source text in SDL/PR form, translates the source text into the graphical SDL/GR form and plots it on a line printer. (See also [6].)

[1] A "state" is a point in time when the protocol process is at rest waiting to receive one of several possible inputs.

b) For the user of the switching equipment (the "telephone operator"), SDL offers a method of presentation of the behaviour of the system, that:
   - for its staff, is easy to learn, to interpret and to use,
   - for its management, provides unambiguous specifications and/or descriptions for tendering and examination of offers, with the capability of meaningful comparisons between competitive types of SPC switching systems.

2. A brief overview of SDL language

2.1. A layman's naive view of the SDL: a layman looking at an SDL diagram for the first time might easily see it as a string of pennants hanging from a mast. Were that not enough, the SDL instructions fill such a impressive number of pages in the relevant CCITT books that he will probably think he is handling a manual of nautical instructions or illustration of the flags which vessels invariably fly during full dress reviews or when an international sailboat race is about to begin: indeed, this analogy would be perfectly valid but for the lack of colour in the SDL "flag" symbols.

2.2. Far from being as arcane as our layman would imagine, a few explanations to the novices in reading SDL diagrams suffice to show them that the SDL language is in fact crystal clear: its alphabet and syntax are so perfectly simple as to make it a *universally comprehensible* language.

SDL has an extremely reduced alphabet consisting almost entirely of the symbols we have likened to flags: these represent the input and output of a system "machine" (more exactly for an SDL diagram, the input and output of a process) (Fig. 1). The alphabet is supplemented by a small number of ideographic symbols. As in the script of ancient Egypt, cartouches are also used where necessary to enclose explanations in ordinary written language, most generally by use of abbreviations.

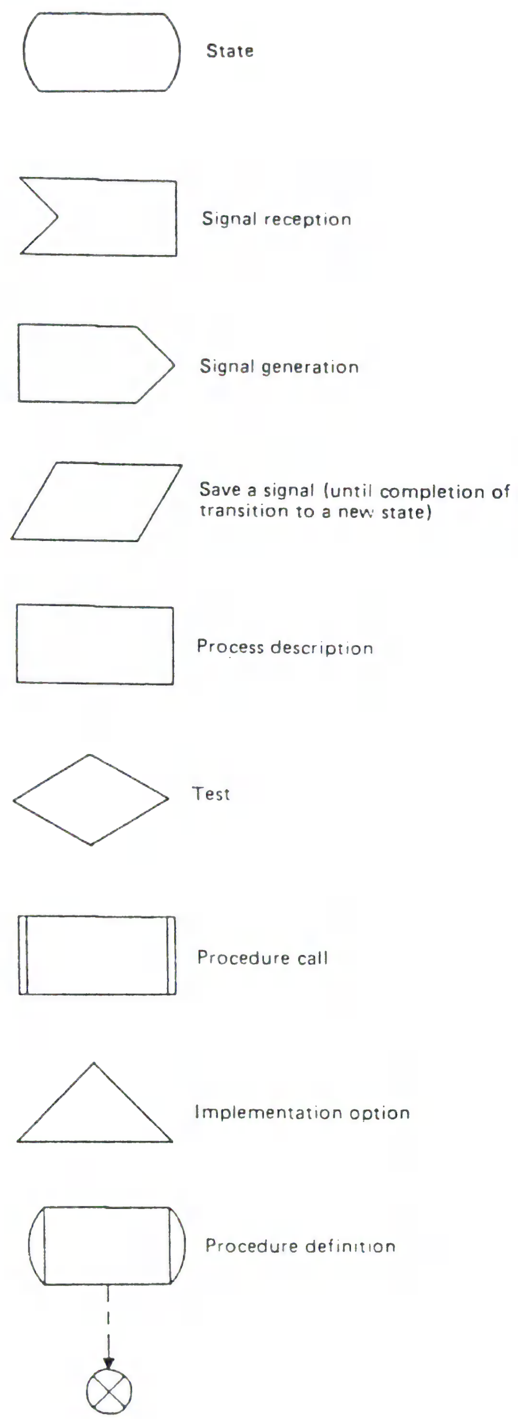

Fig. 1. Symbols and definitions to be used in describing states.

As a language of symbols, SDL might be termed an ideographic language and, since the number of ideograms it contains is reduced to a minimum, it might even be termed a basic ideographic language.

2.3. Reading SDL diagrams is child's play as are the rules for writing in SDL. As a result, SDL has now become the genuine *"esperanto" of specialists in the telecommunication world.*

Practising what it preaches for once, when it comes to specifying sequences of processes the CCITT now systematically resorts to descriptive SDL diagrams [2]. Specifications laid out in that way are unequivocal: indeed, they are as precise as an algebraic formula. There are none of the dificulties of interpretation associated with texts written in ordinary language, as used to be the case a few years ago, and this is an even greater advantage since many readers of the CCITT Books have to come to grips with subject matter that is described in a language other than their own.

2.4. As in the case of any other script, the preparation of SDL diagrams involves the intellectual ability of the drafter who must know precisely and in the smallest detail what has to be written into each diagram. Those who draw up specifications and program them in SDL thus have to master the difficult art of knowing all the external events likely to become involved, of foreseing every possible selective choice as well as the time factors to be taken into account in the sequential chain of events. Just as with every written language, therefore, many can read SDL but only a relatively few qualified experts can write its diagrams.

[2] e.g., for the specifications of CCITT Signaling System No 7, of interworking between international signaling systems, etc.

3. Practices and theories in which distant influences on the formulation of SDL can be discerned

A work of technological history like this would be incomplete without a hint as to the many and sometimes remote antecedents discernible in the origins of the SDL. First of all, the language is quite obviously a direct descendant of the systems of flowcharts, so widely used by computer and electromechanical switching system designers. Less well known is the fact that it owes even more to the "state-transition-diagrams" theory which itself is a derivative of the theory of the operating principles of the "sequential machine" (see Box A and Figs. 2 and 3) [7].

It is to Kawashima [8] that credit must go for having been the first to show, in 1971, the usefulness and fertility of the "state-transition-diagrams" theory for representing the functional specification of a SPC switching system by sequential machine principles [9] (see Box A). Such diagrams were widely used in Japan in the 1970s and quickly found favour among switching software specialists the world over.

An application of the sequential machine principles was the concept of the "finite-message-machine" (see Box B). This concept, often associated to the one of "Virtual machine" (see also Box B), was largely used in the software architecture and design of several switching systems developed during the late 1970s and early 1980s.

Box A

The sequential machine [7]

During the 1950s, many new concepts and/or applications of concepts developed in the late 1930s by mathematicians, especially those of the topology discipline, were used, mainly in the Bell Laboratories, to form the basis of what was to become a truly scientific "switching theory". That theory was intended to rationalize the intricate design of the circuits of electromechanical switches, a task which until then had been virtually a craft exercise performed by very few specialists.

Besides the application of Boolean algebra to the design and analysis of logic circuits (C. Shannon) [3)], another particularly important concept for the design of common control switching systems was the application of the automata theory to the telecommunication field. (This theory benefitted from all the highly abstract if not philosophical analyses of how automatic machinery and particularly computers operate, work on which the British scientist Turing and his "ideal machine" have left their mark). For the analysis and synthesis of sequential circuits, formal methods of *finite-state automata* were formulated by E.F. Moore [11] and G.H. Mealy [12] [4)]. Their models decomposed sequential circuits into a combinatorial part and a memory part, exactly in the image of a computer device. The finite-state machine, some years later, became a theory to be largely used in software analysis (see Box B).

In the sequential machine concept, the status of output circuits depends on that of the inputs – not simply those injected (what is called one "stimulus", or several) when the machine is operating but also those already available. This presupposes a store, hence the standard configuration of the sequential machine (Fig. 2) [13].

Sequential machines can be regarded as operating independently of time constraints (asynchronous mode). This immediately raises difficult problems since elements stored in the memory may vary with time. Hence the need to provide *a time division* to ensure that each operating situation corresponds to a clearly identified moment, and for *a clock* to ensure that there is no deviation from the set intervals. The next development was *synchronous operation*, with clock pulses to pace the operations according to clearly defined intervals (Fig. 3).

These theories of the operation of automatic machines apply to many types of machinery other than telephone systems. For such systems, they were most useful for formalizing the many operations which take place in a telephone exchange.

[3)] This gave rise in 1951 to the publication of the famous book "Design of Switching Circuits" by Keister, Ritchie and Washburn [10] and to the popularization thereafter of the basic Boolean elements – including the "exclusive OR" and "NAND-NOR" - for assembling the components of all electronic devices.

[4)] The names of "Moore machine "and "Mealy machine" were conferred in the 1950–1960 technical literature on two slightly different types of the sequential switching machine. See the important bibliography on the subject in [12].

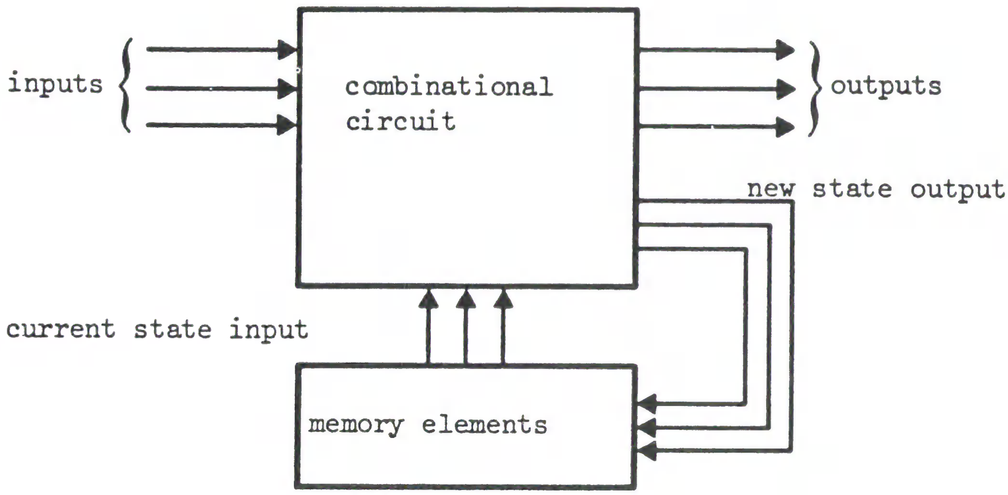

Fig. 2. The sequential machine.

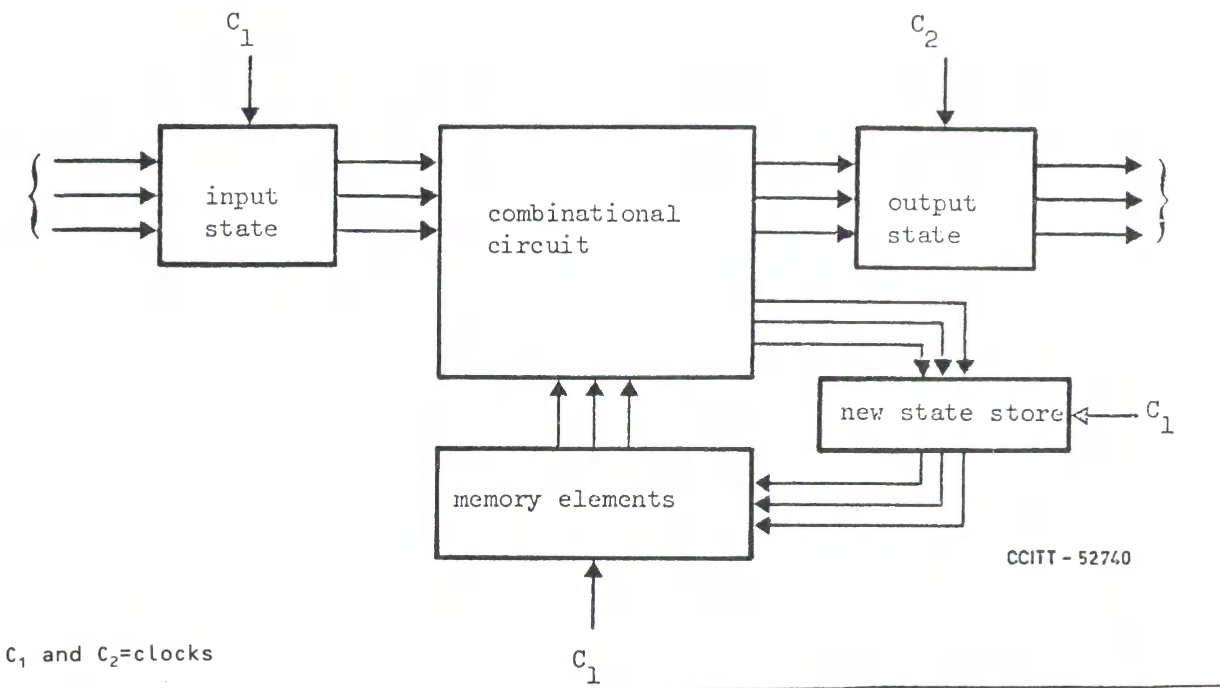

Fig. 3. The sequential machine (synchronous operation).

In Figs. 2 and 3, the outputs of the sequential machine are a function of:
– the inputs from the external environment,
– the internal state of the memory.
The internal state of the memory is modified by the outputs of the sequential machine.

Box B

The virtual machine concept [14]

Virtual machines offer a well known software design technique which makes it possible to structure the functions of a system in such a way that programs on higher levels of the virtual machine do not need to know details about the implementation of functions on lower levels.

This structuring of functions into a nesting of several levels of virtual machines is the support of the modular structure of the software of many SPC systems.

The Finite Message Machine [14,15]

The "Finite Message Machine" (FMM) concept, another basic concept of the sequential machine theory, is also largely used in software architecture. FMMs will then constitute the basic software modules which control all exchange functions. They will be black-box software entities, with their internal structures unknown to the rest of the software, FMMs being independent of each other in that they will not have shared local data. All data required by an FMM is uniquely owned and updated by the FMM as a result of messages received from other FMMs.

In some SPC systems (e.g., the Alcatel System 12 [14]), FMMs are compiled, linked and loaded as a total package for particular exchange configuration. Thus the FMMs represent a set of building blocks such that the software of an exchange can be arranged and put together to satisfy any specific requirement.

4. Deployment of SDL

4.1. From the late 1970s and particularly the early 1980s, SDL enjoyed great success. First, of course, among those who had played an active part in drawing up its specifications (switching manufacturers in the main) but very soon afterwards among telephone operating agencies as well (see [16–19] and, for a later period, in AT&T [20,21]).

The proponents of SDL were extremely active in those years.In addition to the formal specification of the language in CCITT Recommandation Z.100, their initiatives were reflected in 1988 in further CCITT publications, namely:

- "SDL User Guidelines" [22],
- "SDL Formal Definition: Introduction. Static Semantics. Dynamic Semantics" [23].

An SDL Implementors Forum was instituted and met fairly regularly (e. g.[24]). The bibliography of articles and papers written on SDL and inventorized at the Forums occupies whole pages of their Proceedings. An "SDL Newsletter" was published, with R. Saracco (Italy) as editor, and circulated among SDL users [25].

4.2. In recent times, the most ardent supporters of SDL are to be found in the newly industrialized countries and the developing countries.

a) To the former, i.e. those countries which launched into the manufacturing of SPC switching equipment, the discovery of SDL - and also CHILL – came as manna from heaven and, as high-quality and immediately available work tools, they were used from the outset to design the systems of, inter alia, Brazil [26], South Korea and India [27], which were on the point of setting up national switching industries of their own when the two languages appeared.

b) Because they have no switching industries of their own, the developing countries are a prime target for the multinational switching groups which compete fiercely for the export contracts they have to place. As a result, systems

from different sources often co-exist in one and the same developing country. The use of SDL is now a mandatory requirement in the specifications of systems put out to tender by those countries, not only to permit the objective comparison of bids but also to ensure that the system descriptions passed on to maintenance personnel are uniformly drafted.

Moreover, the latter argument holds good for all countries, whether industrialized or developing, since telephone agencies have to see to it that their entire staff have access to only one standard mode of description.

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CHAPTER VII-4

"CHILL", THE CCITT HIGH LEVEL LANGUAGE FOR PROGRAMMING SPC SWITCHING SYSTEMS

1. Birth of CHILL

1.1. A review of the existing High Level Languages for programming SPC switching systems [1–2]

According to the decisions of the CCITT 1972 Plenary Assembly, CCITT S.G. XI was officially entrusted with the study of a High Level Language (HLL) for programming SPC switching systems.

The work started in 1973 with a large and detailed enquiry into existing HLLs and their essential characteristics, then to their evaluation. The list of HLL languages offered to the CCITT examination was a long one: twenty seven, including all the variations which some of them had already undergone. For both technical and political reasons (there was no way that a language adopted by a given manufacturer could be selected as the sole universal CCITT language), the conclusion of this study was that none of these languages were satisfactory for the intended application. Indeed, none of them met the requirements hereafter listed under 1.3 for what was to be the CHILL.

1.2. Study of a new language [2–4]

In 1975 an *ad hoc* group chaired by R.H. Bourgonjon (Philips, Netherlands) was formed to handle the development of a "new language". A preliminary proposal was ready for the 1976 CCITT Plenary Assembly. In the following study period (1977–1980), it was decided to evaluate and enhance this proposal by trials in order to gain practical experience with the new language and complete its definition. A team of language specialists was formed, also under the chairmanship of R.H. Bourgonjon. From late 1975 to 1977 they prepared a draft proposal for the new language.

This draft was known as the Blue Document. Although this Blue Document did not contain a complete language, several trial implementations with compilers converting the new language programs into machine code of various switching systems were initiated by different organizations. The results of these trials were collected and extensively evaluated over the next two years by the "Implementors Forum". The final language proposal was completed by the end of 1979 and presented in the form of a Brown Document. The 1980 CCITT Plenary Assembly approved as Recommendation Z.200 the definition of what was then christened the CHILL language (CHILL for Ccitt HIgh Level Language). After translation into French, the resulting document became known as the Gold Document [1] and was published in printed form by the ITU-CCITT.

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[1] "This flirtation with colours was a recent phenomenon in computing. A remarkable similar activity to that of the CCITT was initiated by the American Department of Defense in 1975. The goal was to establish a single high level language for DoD embedded computer systems. A set of requirements for a language was published and successively refined in various documents until June 1978. After existing languages had been studied and considered unsuitable, four new languages were commissioned. They were respectively known as Red, Green, Blue and Yellow. The eventual winner was Green and renamed ADA in honour of Ada, Lady Lovelace, the Charles Babbage's programmer." [4]

Several comparative studies of CHILL and ADA have been made, see for example [5] and [6].

1.3. Several *requirements for CHILL* had been listed at the start of its development: it had to be suitable for the following applications:
- call handling
- test and maintenance
- operating system
- on-line and off-line support
- implementation of Man-Machine Language
- acceptance testing.

2. Qualities of CHILL

CHILL met all the above requirements. Derived from PL/1, ALGOL 68 and even more from PASCAL, CHILL includes high-level control structures (such as the DO WHILE, IF THEN ELSE, CASE, etc), comprehensive compile-time, mode-checking facilities, plus the normal arithmetic, relational and Boolean operators for evaluating expressions. As a result, CHILL is a flexible yet powerful machine-independent language and its source text provides highly efficient and robust object code.

CHILL is considered as an efficient tool for writing all kinds of programs for SPC exchanges, which covers a wide range of computer programming. Moreover the language is considered to be general enough for a number of other applications as well.

For switching equipment manufacturers, the advantages of CHILL in the design of their equipment are several and are quoted for example in [7] as:"clear structure, readability, transparency, portability and short development time of the source code, plus the additional facilities for sophisticated data definitions and concurrent processing".

3. Publications on CHILL

3.1. Besides the "CHILL Language Definition" published as Recommendation Z.200 in the CCITT Book, (Fascicle X.6 of the 1989 CCITT Blue Book), there are several official CCITT publications on CHILL:
- from the most elementary nature: an "Introduction to CHILL" (1983) (a text officially finalized after four previous draft versions!), of the type and style of instructions for the apprentice programmer to any software language,
- to the most scientific and esoteric nature: a "Formal definition of CHILL" (1982), based on both BNF grammar and the "Vienna Development Method" (VDM) [8] in a basic approach of Denotational Semantics.

3.2. Once the CCITT had formalized CHILL in 1980, proponents of the language fell over each other in announcing the good news and preaching the merits of their new language. Examples of the numerous papers and articles on the subject will be found in [9] to [16] [2].

A whole series of initiatives was also taken by members of the CHILL working group (Chairman: N. Martelloto, of AT&T) of Working Party XI/3 (Chairman: D. Roche, U.K.) of CCITT Study Group XI:
- A "CHILL Bulletin" was launched to enable users to echange views and report all publications on the subject. There are now more than 100 of these.
- CHILL Conferences were regularly organized:
  * the first in Copenhagen in 1980
  * the second in Lisle (Illinois) in 1983 (with the presentation of a CHILL Tutorial),
  * the third at Cambridge University (U.K.) in 1984,
  * the fourth in Munich in 1986,
  * the fifth in Rio de Janeiro in (March) 1990.
- National publications appeared on CHILL, particularly in the form of translations of the "Introduction to CHILL" handbook in such languages as Chinese, German, Italian and Japanese, and of other training documents in Spanish, Norwegian, etc.

Documents relating to CHILL are very formal; they require many different type-fonts and

[2] The references here quoted have been selected in a preferential manner from the various ISS Proceedings, as documents largely published and easily available.

very precise typograph and are therefore extremely difficult to edit. The maintenance of the official CHILL documents requires sophisticated computerized tools which e.g. automatically produce an index of production rules, a collected syntax, etc. A "TEX" text processing system, acquired by the ITU Computer Department, now maintains the processing of CCITT texts on CHILL.

4. A CHILL description

The description of CHILL fills an entire CCITT volume of very many pages. For those who are unfamiliar with the language but would like to know a little more about it, Box A below contains a brief account of its main characteristics, based on a succinct extract from the descrip-

Box A

A CHILL language overview
[from CHILL User manual (CCITT)]

1. A CHILL program consists of three parts. There is a description of the *actions* which are to be performed, a description of the *objects* which are manipulated by these actions and a description of the *program structure*.

Data objects are described by *data statements* (declaration and definition statements). Actions are described by *action statements*. The program structure is determined by program *structuring statements*.

2. Data objects and modes

2.1. Data objects are the entities manipulated by the actions of a program. A *data object* is either a *value* or a *location*. A location can be thought of as an abstract container where values can be stored. (A location should not be confused with physical memory units). A *location* declaration allocates a location, into which a value may be stored, and attaches a name and a mode to it.

2.2. CHILL is a "strongly typed" language: data objects have a *mode* attached to them. The mode is a set of properties common to a set of data objects. The mode of an object defines the set of values which the object may assume, the access method if the object is a location, and the valid operations on the values.

Discrete modes are those attached to objects having a finite ordered set of indivisible values. Some of the standard CHILL discrete modes are:

- INT = integer
- BOOL = Boolean
- CHAR = character
- etc.

2.3. *Composite data objects* may be built by aggregating more simple objects. One way of building composite data objects is by means of *arrays*. An array is composed of objects of the same mode. Each object is called an *element* of the array. An array of an array (a matrix) is again a perfectly ordinary mode, and it may be used in a declaration.

Another way of building composite data objects is by means of *structures*. A structure is composed of objects of possibly different modes. Each component object is called a field of the structure.

Arrays and structures are defined as specific types of mode. Another type of mode is the *string mode*, i.e. a special kind of arrays whose elements are characters or bits.

2.4. *Expressions and assignment statements*. An *expression* is used to compute a value. It consists of a list of *operands* connected by *operators*. The value delivered or yielded by an expression may be stored in a *location* by means of an *assignment statement*.

Box A (continued)

3. Actions

Actions constitute the algorithmic part of a CHILL program.

The *assignment* action stores a (computed) value into one or more locations. The *procedure call* invokes a procedure, a *built-in-routine call* invokes a built-in-routine. To return from and/or establish the result of a procedure call, the *result* and *return* actions are used.

To control the sequential action flow, CHILL provides the classical flow-of-control actions: IF (for a two-way branch), CASE (for a multiple branch), DO (for iteration), EXIT, CAUSE (for a specific exception), GOTO. To control the concurrent action flow, CHILL provides the START, STOP, DELAY, CONTINUE, DELAY CASE and RECEIVE CASE actions and the evaluation of a RECEIVE EXPRESSION.

4. Program structure

4.1. Program structuring consists of grouping together action and object descriptions which are related.

A most important aspect of program structuring is to control the use of names, i.e. where names are declared or defined and where these names may be applied. When a name may be applied at some point in a program, the name is said to be visible at that point.

An object has a certain *lifetime*. The lifetime is the time during which the object exists in the program. Some objects may have a permanent lifetime, in which case they exist for the whole duration of the program. The lifetime of a location object is important for storage handling because the lifetime determines the allocation and deallocation of storage.

4.2. *Concurrency*, i.e. the possibility of concurrent execution, is a dynamic property allowing that something occurs during the execution of a program. Concurrent execution occurs when two or more parts of a program are executed at the same time, i.e. in parallel. (A telephone exchange is a very typical system with concurrently executing parts. Telephone devices are working in parallel and many calls are in various stages of progress at the same time).

The unit of concurrent execution is the *process*. A process is a dynamic program part which may be executed concurrently with other processes of the program. If several processes are required to accomplish a common task, there is a need for them to cooperate. Then the processes must be coordinated to exchange information at certain points. Another need for coordination arises when several processes are competing for the use of a common resource: then the processes must be scheduled in such a way that only one process gets to use the resource at any one time.

tion given in the "Introduction to CHILL".

(Any language description may be considered to consist of two parts. First there is the description of the *syntax* of the language, i.e. which sequences of characters form *legal constructs* (e.g. the "data objects" in CHILL) in the language. Second there is the description of *semantics*, i.e. the meaning of these constructs.)

5. Deployment of CHILL

5.1. As a CCITT-standardized language, CHILL is very different in nature from its twin brothers SDL and MML (Man-Machine Language). Whereas the latter are of chief interest to telephone operating agencies and represent a mandatory requirement in the clauses of contracts they place with switching equipment suppliers, the same does not apply to CHILL. The

decision to use CHILL or not is basically a matter for the switching equipment manufacturer [3]. In international tendering, therefore, the wording of clauses relating to the programming language of a requested SPC system contains far more nuances than in the case of clauses relating to SDL and MML whose use is mandatory. Take the following two clauses as an example:

"The majority of all software programs shall be written in a single High Level Language (HLL). The use of Assembly language shall be minimized."

"The System HLL language shall be an internationally recognized language. The HLL CHILL defined by the CCITT can be considered as an advantage from the points of view of both compatibility in a national network including equipment with a diversity of manufacturing origins, and of the related staff training."

5.2. Most switching manufacturers had not awaited the arrival of CHILL but had gone ahead and adopted their own programming languages, often many years earlier [4]. We saw in section 1.1. just how many of these there were as long ago as 1973.

The decision by an SPC equipment manufacturer to change his programming language is an extremely onerous one in terms of both immédiate financing and long term implications. It is thus no surprising that the impact and use of CHILL essentially started manifesting itself only when a new generation of systems came into being in the early 1980s. Such was the case with the Siemens EWSD system, System 12 (initially ITT but now Alcatel) and all the systems put into production in such newly industrialized countries as Brazil, South Korea and India. In Japan, the 1977 decision by NTT and industry to adopt CHILL for a new version (D100B) of NTT's D-10 space-division system being produced [17], and eventually for all their systems, must be attributed to the extremely active part played by Japanese engineers in the elaboration of the language itself and the clear-sighted appraisal by the management of NTT and Japanese industry of the long-term advantages of systematically using it.

5.3. Equipment other than that used for public switching and requiring smaller sizes of software also offered a substantial field for the application of CHILL. Primarily, of course, among switching manufacturers who systematically use it for the design and development work of all their switching equipment, but also among many other producers of private switching or terminal data processing equipment.

CHILL eventually found a niche in a number of highly specific applications. An example of this is to be seen in the way CIT-Alcatel reconciled its "Operation and Maintenance" software to unify many of the programs for the two systems produced by the group, namely the MT system (initially produced by Thomson-CSF-Téléphone) and the E10B system (of CIT origin). Each system formerly used a separate programming language different from CHILL. The interpreter which translated and reconstituted them in one and the same language with unified software programs was CHILL-based [18].

5.4. Whatever the life and durability of the language used by an industrial group for programming its switching equipment, such languages are not immutable and are likely to evolve in the course of time. The structural characteristics and basic principles of CHILL have exerted and will always exert an influence in this respect.

With the radical concentration of the switching industry now taking place in the late 1980s and the merging of companies that eventually become part of one multinational industrial group or another, the generalization of the use of

[3] Even in the most developed countries, telephone operating agencies are unlikely to employ more than a handful of people – top-flight engineers and some highly specialized staff in a research and/or commissioning department – capable of immersing themselves in the subtleties and mysteries of how to program SPC systems supplied to their agency.

[4] Some commentators on the CHILL expansion consider that CHILL arrived four or five years too late. It is another example of the difficulties encountered by CCITT to obtain at the right time a standard specification on subjects which cannot wait the lengthy processes of international deliberations and formal agreements.

CHILL is likely to be affected substantially in the 1990s.

5.5. On the eve of the 1988 CCITT Plenary Assembly, CHILL received further official confirmation both of its merits and of the absolute strictness with which its specifications had been formulated in Recommendation Z.200: the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) recognized the Recommendation in question as a joint ISO-IEC Standard (No. 9496).

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CHAPTER VII-5

"MML", THE CCITT MAN-MACHINE LANGUAGE

1. Birth of the MML and its enhancements [1]

1.1. "MML" was developed by the CCITT to facilitate operation and maintenance functions of SPC switching systems. It had also to be used for the installation of such systems and for acceptance testing according to national requirements.

MML had to contain inputs (commands), outputs, control actions and procedures to ensure that all these functions could be performed independent of the system.

1.2. As in the case of its two sister CCITT programming languages, studies on MML started during the 1972–1976 study period.

Perhaps in this instance matters were somewhat simpler than the task of developing SDL and CHILL because this time what was wanted was known precisely from the outset. Telephone operating agencies and manufacturers were equally involved and several of the latter (e.g. [2]) already had a wealth of experience in defining and implementing man-machine languages. (No SPC switching system would be conceivable without arrangements whereby maintenance personnel could have access to its control organs.)

By 1976 the CCITT Plenary Assembly was able to approve Recommendations in the Z.3xx series containing the bare bones of MML, i.e. its syntax [1)].

1.3. During the ensuing four-year CCITT study periods, the drafting of those Recommendations was streamlined and enhanced and new Recommendations were prepared:

- to further broaden the field of application of MML and to extend it to non-telephony applications;
- to allow for considerable advances made in personnel activities since the mid-1980s. In a number of systems, operating and maintenance staff now have control desks provided with video display terminals (VDTs). They are as user-friendly devices – or even more – as those found on the keyboard and screen of a PC (Personal Computer). Before the advent of VDTs and the prior development of their sophisticated software which had to take into account all characteristics of the SPC system as well as maintenance processes (including those during the most critical operational phases), operators had to decipher messages, coded in sibylline terms, from the paper tape spewed out by a teleprinter; by means of the same code they then had to use the teleprinter to send messages to the machine. VDT screens now offer windows displaying all the necessary data on the system configuration and the status of its components, etc. They even offer the operator pre-established "menus" to guide him

[1)] The Recommendations defining specifically the syntax of the language are:
Z.302 – The meta-language for describing MML syntax and dialog procedures
Z.312 – Basic format layout
Z.313 – The character set and basic elements
Z.314 – Input (command) language syntax specification
Z.315 – Output language syntax specification
Z.317 – Man-Machine dialog procedures

in any choice he may have to make, thus considerably facilitating his dialog with the machine [2].

2. A MML overview [3]

2.1. Man-machine communication, the means of exchanging information between users and systems, can be represented by a *layered model* in which each layer defines features that support such communication. The *man-machine interface*, represented by *the highest layer* of the model, is based on the repertoire of inputs, outputs, special actions and man-machine interaction mechanisms, including dialog procedures, made available by the layers below. The features offered by the *lower layers* are based on a *MML semantics* associated with each MML function (actions, objects, information entities) and a defined *MML syntax*.

2.2. Basically, four main functional areas are covered by MML: maintenance, operation, installation and acceptance testing. Each functional area is specified in detail by a CCITT Recommendation offering a model to allow the generation of function-related semantics. Two Recommendations (Z.332 and Z.333) provide a methodology for the consistent production of the detailed specifications required for each functional area.

The representation of the information structure associated with an MML function involves the specification of all the information entities needed and their inter-relationships. This representation is achieved in a consistent manner by means of Information Structure Diagrams, diagrams drawn in using a meta-language consisting of a set of symbols and drawing conventions.

2.3. Since the semantics of MML could hardly be simpler (a few graphic symbols and the characters of a sub-set of CCITT International Alphabet No. 5), the description of the language relates essentially to its syntax. This is defined by means of *syntax diagrams* based on those used to describe the Pascal language [4]. A diagram represents the information structure in a top-down approach, starting from the identification of the MML function to be structured and ending with all the information components felt necessary in the man-machine interworking for that function. The decomposition process is performed by the use of *sequences, selections* and *iterations*.

A syntax diagram consists of symbol boxes connected by flow lines. Symbol boxes are of two types:
- *terminal symbol boxes*, i.e. containing a character or a string of characters which actually appear in the input or output,
- *non-terminal symbol boxes*, i.e. containing, within a syntax diagram, the representation of another syntax diagram by name.

Every symbol box and consequently each diagram must have only one entry and only one exit flowline.

2.4. Syntax diagrams of the MML Recommendations specify the syntax of the MML input, MML output and the man-machine dialog.

Input can be from any device that produces the codes of the characters of CCITT International Alphabet No. 5. A keyboard input device is normally used; however, recorded input (e.g. paper tape, magnetic tape, cassette, etc.) may also be used.

Output can be to any device that accepts the codes of the characters of CCITT International Alphabet No. 5 (paper tape punchers, teletypewriters, line printers, visual display units).

3. Qualities of MML

3.1. The advantages of using MML were heralded in several papers delivered at the Paris ISS in 1979; see in particular [5]. Significantly, no further papers devoted specifically to the language were delivered at subsequent ISSs. Indeed, since the early 1980s there has been no doubt as to its many qualities. MML is:
- easy to learn and to be used by novices as well as by experts,
- adaptable to different kinds of personnel and to different national language and organizational requirements,
- flexible, and structured to allow the graceful incorporation of new technology,

[2] Dialog is that part of man-machine communication initiated and, normally, terminated by the user.

- inpired by all recent developments in the "Human factors" science (i.e. in "ergonomy"), developments largely used to characterize the elements of a "user-friendly" man-machine interface with which the user comes in contact either physically, perceptually or conceptually.

The specifications of MML have not overlooked:

- the devices for "access control", with use of "Personal passwords", terminal authorization and restrictions,
- the devices for alerting the operator by "warning" prints/displays, bringing to his attention dangerous commands (dangerous commands per se as well as commands becoming dangerous by using certain parameter values),
- prompting devices with which the machine provides the appropriate parameter name in asking the operator to input the parameter value only,
- etc. [6].

3.2. Given all those qualities, MML has won the general approval of telephone operating agencies and switching manufacturers alike. The CCITT Recommendations have become a universally applied standard in most of the systems in operation and in every system now being developed.

3.3. Today MML is in general use not only at exchange control desks but also at operation and maintenance centers (OMCs) performing the following various functions both in centralized mode and remotely [3].

a) The *Subscriber administration* (Recommendation Z.334), in a administrative environment which depends on each telephone operating agency with its specific degrees of data processing support. The model offered by Recommendation Z.334 describes the way in which subscribers of a public exchange are connected to and managed by the exchange, including data related to the associated hardware in the exchange.

b) The *Routing administration* (Recommendation Z.335) covering system functions that are in charge of routing a call attempt towards its destination on the basis of the data associated with the call attempt (e.g. the dialed digits, etc.) and the data associated with the network (e.g. identities of the circuit sub-groups serving a certain destination, etc.). The destination of a call attempt may be inside or outside the switching system.

c) The *Traffic Measurement administration* (Recommendation Z.336) relating to the production, collection and output of traffic data. In the model offered by this Recommendation, traffic measurements are defined and identified by three basic elements:

- time,
- entities (the measured quantities, such as traffic flow, number of call attempts, congestion time),
- objects (e.g. subscriber lines, circuits, circuit groups, elements of the exchange's switching network).

d) The *Network management administration* (Recommendation Z.337) relating to the supervision of a (large) telephone network and actions to be taken to control the flow of traffic to ensure the maximum utilization of this network in all situations.

3.4. MML has been implemented not only for the maintenance and operation of SPC systems but also for many other applications such as videotext systems, mobile radio systems, PBXs, etc.

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CHAPTER VII-6

YET MORE DEVELOPMENTS IN SPC EXCHANGE PROGRAMMING LANGUAGES

1. Are chapters VII-2 to VII-5 too one-sided?

1.1. Chapters VII-2 to VII-5 may give the impression that everything to do with exchange programming and the languages used have hinged on the work of the CCITT. Nothing could be further from the truth.

Indeed, it must be realized that the work of the CCITT and its ensuing Recommendations or standards relating to SDL, CHILL and MML languages simply marked the conclusion – perhaps we should say the crystallisation – of a vast array of parallel initiatives and studies conducted in several countries over some 15 years. In other words, the descriptions in the preceding chapters are a mirror image of various developments, of which they have the merit of offering a *consolidated view*. Such was the purpose of including them, possibly at the risk of giving them too prominent a place. However, far be it from the authors' intention to cause any underestimation of what was done outside the CCITT and in many countries, often without being reported at CCITT meetings.

1.2. Then again, a clear distinction should be drawn between the case of the CHILL programming language and that of SDL and MML which, as mentioned earlier, are now used by general or quasi-general consensus. As stressed in Chapter VII-4, this is not the case with CHILL which, although adopted by a number of switching equipment manufacturers, is still ignored by many others including some of the largest.

The purpose of the present chapter is not to give an exhaustive description of everything which has not been covered earlier but to mention at least the main developments achieved by different switching equipment manufacturers for programming their exchanges.

2. Reasons for the relatively limited spread of the use of CHILL

There are several reasons which account for the relatively limited spread of the use of CHILL by switching equipment manufacturers.

2.1. The first reflects the fact that manufacturers had, of course, to create their own programming languages long before CHILL was defined. For instance:

- in the United States, only an assembly language had been used until the early 1970s when the more evolved EPL language was introduced in the Bell System's SPC equipments produced by Western Electric for programming a part of the ESS 4, AT&T's first digital system. Subsequently, the C language developed by Bell Laboratories became and still remains the chief "switching" language, particularly for programming the ESS 5;
- again in the United States, GTE chose a simplified version of PASCAL language for programming its GTD-EAX 5;
- in Canada, Bell Northern Research (BNR) uses their own PROTEL (Procedure Oriented Enforcing Language) and a version of PASCAL for the DMS family programming

- in France, CNET had defined the PAPE language which was used for most of the exchanges produced by French manufacturers;
- LM Ericsson had adopted and is still using the PLEX language for its AXE system. (Although PLEX inspired the definition of very many features of CHILL, it cannot strictly speaking be regarded as a specific version of CHILL);
- in Japan, a DPL language developed by NTT was used for the D.10 and D.20 series of exchanges prior to the 1977 NTT's decision to switch to CHILL;
- the European companies of the ITT Group used the ESPL/1 language before joining in the late 1970s the move to CHILL.

To a switching manufacturer, converting from a widely used language to a new standard one is an exercise as restricting as it is costly, particularly if it affects a considerable volume of established instructions which, nowadays, often run into several million lines. Nor is only the program library affected: first in line are the large number of programmers who have to be taught the new language. There is also the equally large stock of machines, such as compilers, which have to be adapted to use the new language.

It is therefore virtually amazing that in spite of such constraints some manufacturers should have unflinchingly taken the plunge and adopted CHILL as their standard company language. Such was the case of Japan under prodding from NTT, of Siemens in the Federal Republic of Germany and, lastly, of the ITT Group. In all these cases the decisions may be said to have been taken among nebulae, i.e. clusters of industrial companies under a common umbrella which was keen to have all its dependent companies observe linguistic uniformity. In this respect Japan was typical.

2.2. A second reason has helped to check the use of CHILL by telecommunication equipment industries, whether they be in switching for which CHILL was essentially intended or in any of the many other applications for which it would be equally suitable. Very often, such industries also engage in the production of electronic equipment for applications other than civil telecommunications, particularly military applications. Government defense ministries subject their orders to specific requirements of their own and these are even tighter than those imposed by national telecommunication operating agencies. In some countries, misgivings about the use of CHILL have been strengthened by moves to impose the use of military standards such as the ADA language, a contemporary and in truth almost an equivalent of CHILL. With an eye to the cost of training ranks of programmers in their software laboratories, electronics manufacturers are very wary of adding to the number of languages used in their companies.

2.3. A third and certainly more important reason has to do with the fact that, to a telecommunications operating agency, a knowledge of the exchange programming language used – while not completely useless – can only be important to a very small number of persons: a few high-level engineers in the research department, plus the handful of employees responsible for inspection testing the switching equipment. Quite unlike the cases of SDL and MML, therefore, and as far only one programming language (or at best a minimum number of them) is used for all the exchanges in an agency's network, the agency itself is wirtually indifferent as to which language is used.

2.4. The geographical distribution of CHILL or of this or that other programming language throughout the world presents us with a genuine mosaic of countries. The pattern reveals large spheres of influence with an absolute or relative preponderance of CHILL in Japan and many other Asian as well as European countries, contrasting with a virtually total absence of CHILL from North America where the C language developed by Bell Laboratories is preponderant ... [1)]

2.5. One thing is of course self-evident: a programming language can spread only as largely as the switching systems for which it has been chosen. When all is said and done, and given

American predominance in the number of SPC exchanges in use, it follows that AT&T's C language should at present be in the forefront of the "switching" programming languages. Without going into the peculiarities of this or that one of the small number of languages other than CHILL or C, let us now briefly turn to C language, its background and history.

3. Background of C language within AT&T [1A,2]

3.1. Until the late 1960s, the software for SPC systems – which at the time simply meant AT&T's ESS systems Nos. 1, 2 and 3 – consisted of a mix of assembly language and macro-instructions [2].

The introduction by Bell Laboratories of a certain codification and standardization into this hybrid language led to the fairly short-term use of a language known as the Switching Assembly Program (SWAP). In the early 1970s studies to develop software for the ESS No.4 resulted in the timid introduction of a high-level language – the one known as "EPL" - which was used in conjunction with the macro/assembly mode then current.

3.2. Over the years there was a steady growth in the volume of AT&T's ESS software owing to the addition of new features and enhancements offered by such systems. At the same time this was matched by a constant evolution in the environment in which software was being developed, an environment always more sophisticated and offering numerous added capabilities [2]. New and more powerful processors appeared and considerable advances were made in software engineering (e.g. structured programming, high-level languages, etc.) [3]. All these factors combined to lend a new approach to AT&T's software production methods. And this new approach, which took effect – or coincided – with the development of the ESS 5 software, found expression in the systematic and standardized use of the language known as "C".

4. AT&T's C language and its history [1,4,5]

4.1. C is a general-purpose programming language which was designed in the early 1970s by D.M. Ritchie in the Bell Laboratories. From its inception in 1973, the C language proved its usefulness for a wide variety of applications. By 1980 it had grown to be the prime programming language of Bell Laboratorie, working on diverse hardware. Not unsurprisingly, C became the programming language of the ESS 5 software.

Initially, C was a general programming language designed for use in time-sharing processes on the various machines in the Computer Department of the Bell Labs. It emerged as the product of several years of evolution and enhancements. "In designing C, Ritchie sought to match the expressive capability of the international style of his time as closely as possible to the hardware capabilities of real machines" [1b].

4.2. One of the first C applications was a personal work of Ritchie to be used in conjunction with the "UNIX" [3] operating system [4], devised in 1969 inside Bell Laboratories on the personal and ingenuous initiative of Ken Thompson. The

[1] Some writers have suggested a correlation – a purely psychological one based on a differentiation between countries living in quasi-autarchy and those with a more outward-looking disposition – between the use of the metric system and of a language which has had the merit of being defined internationally and receiving the label of a "standardized language". There is certainly some truth in this analysis, however shaky the correlation drawn.

[2] For the layperson: a "macro" is a tailored sequence of computer instructions.

[3] UNIX is a trademark of Bell Laboratories. This comment covers every mention of UNIX in this Chapter to avoid the need for repetition each time the name appears.

[4] For the layperson, definition of an "operating system": the software that controls the management and execution of programs.

Box A

The UNIX story
(from [1c] and [6])

The UNIX story begins in 1969 with Ken Thompson's work in the Bell Laboratories on a cast-off PDP-7 minicomputer. He and the others who soon joined him had one overriding objective: to create a computing environment to their own taste, where they themselves should comfortably and effectively pursue their own work-programming research. The result was an operating system of unusual simplicity, generality and, above all, intelligibility. A distinctive software style has grown up upon this base. UNIX software works smoothly together; elaborate computing tasks are typically composed from loosely coupled small parts, often software tools taken off the shelf.

UNIX grew and flowered. In the early 1970s, visitors had flocked to the attic room where the Thompson's machines were housed. Because the UNIX system was the first, and also the most capable, operating system then running on the popular Digital Equipment Corporation PDP-11 minicomputer family, other projects in Bell Labs, the Bell System and universities adopted it straight from the laboratory. By 1972, UNIX systems were doing word processing in the Bell Laboratories, work scheduling in the AT&T Long Lines test room, and were handling trouble reports for No. 5 crossbar systems in a Bell Operating Company. None of these applications took more than three months to develop and install. In 1975, external licensing of UNIX began under Western Electric auspices.

Until 1977 the UNIX operating system and its variants ran only on computers of the Digital Equipment Corporation's PDP-11 family. In an interesting exercise in portability, S.C. Johnson and D.M. Ritchie exploited the machine independence of their C language to move the UNIX operating system and the bulk of its software to different machines. From the early laboratory versions, UNIX emerged then as an industry standard providing portability, performance and power, from microcomputers to mainframes.

UNIX Operating Systems became the internal operating system of the Bell System. As advances in computer architecture were introduced, UNIX provided the solution to the expensive "software recoding". UNIX Operating Systems were developed by Bell Labs to serve as development tools and flexible operating systems for their research needs and for use in telecommunication systems.

UNIX story (see Box A) is quite famous in computer science, as are the successes of this operating system which is now so widely spread throughout the world on thousands of machines, ranging in size from mainframes to microcomputers from a very large number of manufacturers.

UNIX and C language have subsequently developed hand in hand in what could be best be described as a perfect symbiosis. "The success of UNIX was due in no small part to the C language in which it and most of its associated software are written" [1b]. Their association has given birth to a swarm of all sorts of applications.

4.2. UNIX Operating Systems provide a standard for a lot of applications other than telecommunication systems, especially:

- text-processing utilities (editing, transformation, analysis and typographical publication),
- electronic mail systems,
- multivendor networks,
- compatible small systems,
- microcomputers, and
- office automation equipment.

For such purposes, they have been licensed to many software and hardware companies (e.g. Intel, Motorola, Honeywell-Bull, etc.), especially for use on small and medium-sized business sys-

tems. Already in 1984, it was considered that about 100,000 programmers were writing UNIX software [7].

These successes of UNIX, mainly due to its versatility and portability, were accompanied by the appearance of many versions and variants. In an effort to standardize UNIX, AT & T Technologies introduced in 1983 the "UNIX System V version" – a highly portable, multi-tasking, multi-user operating system designed for use in virtually any computing environment, from office automation to software development. Marketing of UNIX then became an important financial activity of AT & T [8]: an example of these AT & T efforts was the formation of a company, called "UNIX Europe", under AT & T and the Italian Olivetti, to promote UNIX as a *de facto* standard computer operating system in Europe.

4.3. The characteristic features of C in language science were:

- a coherent model of pointers and arrays that correspond to machine addresses and yet maintain machine independence;
- a rich set of operators that correspond to typical computer instructions (binary arithmetic operators, logical operators, relational operators);
- a terse syntax that makes programs compact and readable,
- modern control flow and data structuring capabilities, and
- economy of expression.

Strictly speaking, in a hierarchy of languages C could not be considered as a "very high-level" language nor a big one. But it has the major advantage of not being specialized for any particular area of application. It is not tied to any particular hardware or operating system, and its generality makes it more convenient and effective for many tasks than supposedly more powerful languages.

4.4. C language was the product of several years of evolution

Many of its most important ideas came from its immediate programming ancestors in the Bell Laboratories: the BCPL and, later, the B language written in 1970 by Ken Thompson. These two languages, like C, were rather low-level in that they dealt with the same sorts of objects that most computers do. While BCPL and B confined their attention almost entirely to machine words, C widened its horizon somewhat to characters, integers, and floating-point numbers. None of them, however, dealt directly with composite objects such as character strings, sets, lists or arrays considered as a whole. Higher mechanisms for storage allocation and I/O had to be provided by explicitly called routines from libraries.

A main reason for the initial design of C language had been the desire for scientific calculations to provide it with floating-point arithmetic. One major advance to this effect was its "typing structure": each declaration in a C program specifies (sometimes implicitly) a *type*, which determines how much storage the object requires and how it is to be interpreted. The original fundamental types provided were: single character (byte), integer, single-precision floating-point and double-precision floating-point. Others were added later. The idea of "type" corresponded to the general trend inspired by the influential languages of the time, especially Algol, Fortran and PL/1. By the time C was created (circa 1972), advocates of languages like Algol 68 and Pascal, on psychological and human factor grounds for programmer intelligibility, recommended an even more strongly enforced type structure.

In addition to its basic types, C provided a conceptually infinite hierarchy of derived types which are formed by composition of the basic types associated with pointers and declarations of arrays, structures, unions and functions. A "structure" is an aggregate of one or more objects, usually of various types, which can be treated as a unit.

4.5. Although compilers or interpreters initially were made available under C and UNIX for Fortran, Algol 68, Pascal, etc., very little use was made of these conversions. Although C is a relatively low-level language, it was not only adequately efficient to prevent programmers from resorting to assembly language, but also sufficiently terse and expressive that its users prefer it to other very large languages.

Ritchie and his fellow-workers who designed C were quite explicit on the avantages of a design on only one site and not by committees [4a]: " A language that doesn't have everything is actually easier to program in than some that do. The limitations of C often imply shorter manuals and easier training and adaptation. Language design, especially when done by a committee, often tends towards including doubtful features, since there is no quick answer to the advocates who insist that the new feature will be useful to some and can be ignored by others. A feature which is not used often enough to be familiar ... would be better left out."

4.6. As was the case when EPL language was introduced for designing the ESS 4 software, the strategy pursued by AT & T for programming its switching equipement has always been an essen-

tially pragmatic one. The objective has been to introduce advance software tools and techniques in a graceful and timely way and secure for them the commitment and support from programmers at large.

Tuscany describes in [9] how the ESS 5 software was and still is developed using C language in the software environment of Bell Laboratories:

"The ESS 5 software source exists as individual C files. These C source files are logically grouped into compilation units called "functional modules". The compiled functional modules are link edited together to form functional switching subsystems. Finally, the subsystems are linked together to form the ultimate switching system configuration." [8a]

This description of the conventional process of modular development of switching system software could in fact apply to any present-generation system except for the use of C language. However, this points up the highly specific nature of C language, i.e. its division into many single-purpose files. At the end of his article [9b] the author stresses the incalculable advantage to the development of ESS 5 of the oneness of the C/UNIX environment in which a large number of different kinds of processors had to work to produce its software.

5. To conclude chapters VII-2 – VII-6, a retrospect of programming for SPC exchanges

5.1. From the early 1970s onwards, the flood of microelectronic products has substantially modified the architecture of SPC switching systems. Microprocessors had made their appearance and, more important still, memories offering faster access and ever greater capacities had become available on the market. It was the availability of these components that enabled time-division digital switching systems to be developed and led to the design of their two sucessive generations: first the one with centralized control, followed by the distributed control generation (see this classification in Chapter I-2, section 3, Box B).

These developments in the basic components of SPC systems and their architecture brought about a substantial change in the means employed for programming their exchanges.

Until near the end of the 1970s, the small capacity of memories meant that they had to be used sparingly, particularly in programming the more repetitive instructions relating to call handling processes. Accordingly, such instructions were programmed in assembly language and the programming had to be tailored to the hardware of each specialized organ.

While storage capacities were rising and memory cost falling, a very large increase was taking place in the volume of software needed for an SPC system, e. g. for new user-facilities or new versions of the system. This in turn led to ever higher software production costs and a considerable increase in the number of programmers needed. Thus, in spite of the increased use of memories (say, between 20 and 40%) that high-level languages entailed, such languages were introduced to increase the productivity of programmers. This in turn led to research and development in special languages for programming switching systems, with a three-pronged approach reflected in:

- SDL for specifying and describing the system;
- MML for controlling and administering the exchanges in the system;
- CHILL and other "in-house" languages for the actual programming of the exchange operation within the system.

Thus, there was a radical swing in the industrial design of switching systems, with the emphasis falling not so much on hardware as on software. It became a matter of providing the most efficient tools to all who had to work on the system, be they designers (SDL, CHILL or any other programming language) or technicians down the operating line (MML). Intelligibility and the mode of presentation of the programs – for instance, to the operating technicians working on visual display consoles – became a major preoccupation. (These last features contributed much to the commercial success of some systems.)

While the ranks of programmers required for system design and its enhancements were swelling, a change was coming about in the organization of their workshops where all the techniques

of software engineering were converging and being applied. They became what was sometimes called a "software factory". Nowadays, the production methods of this branch of industry are virtually comparable to those of the present-day automobile industry: it is a matter of assembling separate components – here, in the form of program modules which, although constructed independently, are all subject to the strict common discipline of the system to which they belong. The assembly of these modules and their storage in a master library are becoming increasingly critical as the volume of programs in each system steadily expands. This is now evident in the edge which the operating system used for assembling the program modules has gained over the earlier preoccupation with providing the modules themselves with programming by the most compact tools. This probably explains the lesser interest at present in developing languages specifically intended for programming SPC systems, no doubt reflecting a less economy-oriented approach to the use of memories by the system architecture. Every industrialist who has adopted this or that programming language for his system now sticks faithfully to it.

5.2. Developments in the late 1980s are mainly concerned with the increasing automation of program production. The trend almost everywhere is:

- to establish the program first in the form of graphic diagrams which must be highly intelligible, particularly for the agency operating the system (this is the SDL/GR stage);
- next, to translate the diagrams into program instructions (corresponding to the SDL/PR stage);
- and lastly, to convert these program instructions into the programming language of the system, i.e. CHILL or any other standardized language peculiar to the manufacturer.

5.3. Other developments, begun long ago but advancing more slowly, relate to *automatic program validation*:

- verification of the validity of program modules before they are incorporated into the system software, and
- a final check to ensure that the system software functions properly as a whole, even in situations that were virtually unforeseeable at the time of initial specification.

When exchanges of a given system are to be introduced for the first time into a network other than the one(s) for which the system was originally designed [5)], such arrangements have or should have a vital role to play in avoiding lengthy periods of acclimatization in its new environment (and even, sometimes, in saving the reputation of the system).

5.4. Finally and to conclude Part VII, it has to be recognized that the most successful switching systems of today are those whose managers, having designed at least one successful system, were experienced and paid a great deal of attention to the software development process and progress for their system. The importance of making good software development tools available to switching systems designers should be once more emphasized.

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5) In the United States there are offices and software centers – the Northern Telecom's "FAST" service and the AT&T's "FIVE" center – to experiment switching system softwares and verify their compliance to the list of requirements concerning services and features requested by the Regional Bell Operating Companies (RBOCs): a very long list, indeed, since it includes at least 1000 services and features! (see Chapter XI-3, section 4.1).
At the international level, some improvement in the productivity of programming switching systems intended to be deployed in many countries is to be obtained through the work of specialized CCITT groups ("GASP" and "RFQ" groups). Their objectives is to standardize a minimum set of requirements for services and features which may be asked for by the various telephone operating entities and to document them more formally.

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Part VIII

In the 1970s, the digital revolution
The first generation
of digital systems

INTRODUCTION TO PART VIII

What is "digitization"? It is a word which doubtless needs no explanation for the engineer. It is, however, always useful to define one's terms.

An eminent figure in telecommunications, overtaken by a too rapidly advancing technology, one day few years ago, said to one of the authors, "Why has everyone begun to talk about "digital exchanges"? In the automatic system, I simply dial the digits of the number I am calling, so that this is a digital technique, and I cannot see why our good old electromechanical exchanges are not called digital exchanges too." There was a part of verity in his statement. Switching has always been digital since specific indicia are required to positively identify the addresses or directory numbers of telephone stations. Such specificity is inherently digital, but uses the common human numbering base of ten.

In telecommunications, however, what is called digitization is the transmission or processing of binary digits, each of them generally characterized by the presence or absence of a pulse (now, of very short duration).

This was the conventional former technique of telegraph transmission. The emergence of computers since the early 1950s is similarly based on the binary system. The data processed by computers are sequences of binary digits. Data transmission between computers is also inherently of a digital nature.

In the chronology of the general introduction of digital techniques in telecommunications, data transmission was the first field of applications, followed by:

- telephone transmission
- telephone switching
- signaling between distant exchanges

CHAPTER VIII-1

THE GENESIS OF PCM SYSTEMS

"Pulse code modulation has been a child with a long infancy"
Alec A. Reeves

1. An instructive saga

1.1. The genesis of pulse code modulation (PCM) transmission systems must be recounted in this book on switching, since their advent in the 1960s as a result of technological advance due to breakthrough in electronics – the transistor era followed by the integrated circuits era – was the driving force behind the digitization of telephone networks. The standardization and spread of PCM systems were, particularly from 1980 onwards, the launching pad for *digital switching*.

1.2. The story of the PCM concept and its successive developements is a long and exciting one covering five stages:

i) the birth in 1938 of a creative idea and a novel concept, the implications of which passed almost unnoticed at the time, even by their inventor;
ii) studies conducted between 1940 and 1945 in the United States of America for devices of military secrecy in telephony revealed the value of PCM in 1943 and laid the bases for its use;
iii) these ideas matured slowly until the early 1960s when they first took roots in civilian networks, though within a strictly limited geographical range;
iv) in close correlation with advances in electronic components, PCM systems then found their way into long distance routes and had to be internationally standardized;
v) from the early 1970s onwards, either stimulated by the existence of international standards or in parallel with them, the use of PCM systems mushroomed and became the key element in telephone network digitization.

1.3. The story of the genesis of the PCM concept is an extremely edifying one to the engineer and there are two lessons to be learned from it:

1.3.1. Lesson number one: never despair

How long one has to wait for an idea to gain acceptance: Thirty years in the case of the PCM concept!.. It was not until 1965 that Alec A. Reeves, its British inventor, received his first tribute when he was awarded the Ballantine medal by the United States Franklin Institute [1].

May this console the many engineers who have also had brilliant ideas which have not met with immediate success.

1.3.2. Lesson number two: old ideas may prove highly fruitful

Earlier research should not be misunderestimated. It may conceal many ingenious ideas, even if at the time they were stillborn for want of proper technology facilities.

As commentators have not failed to point out *a posteriori*, an analysis of the dual concept peculiar to PCM, i.e. pulse coding and time-divi-

[1] In 1969, the United Kingdom honoured Reeves by issuing a one shilling stamp associating his name with the PCM system [1a].

sion multiplexing, reveals numerous analogies as regards conceptual approaches which may almost be regarded as antecedents.

1.4. Conceptual approaches encountered mainly in telegraphy

1.4.1. The invention in 1874 by the Frenchman Emile Baudot of his famous telegraphy system which was to be so successful for more than fifty years is in all respect comparable with Alec A. Reeves's invention of PCM. Baudot's telegraph multiplex system also used time-division multiplexing of pulses in a telegraph channel and, in addition, was based on the binary coding principle with a five-unit code used for selecting any of the 32 alphabetic characters.

1.4.2. In telephony, L.J. Libois, an expert on the subject and a founding father of time-division switching, refers in his book "Genèse et croissance des télécommunications" [2] to an early American patent, taken out in the names of Pattern and Minor in 1903 and relating to the time-division multiplexing of telephone channels. In the same connection, he also mentions the work of the French engineer Poisson in 1920 and the theoretical studies made by the American J.R. Carson [3].

1.4.3. However, it was again in the telegraphy field that two other fundamental theoretical studies relating to the PCM concept were to emerge from Bell Laboratories in the period between the two World Wars, preparing the way for Claude Shannon's "Mathematical theory of communication" (1948) [4] which founded the celebrated information theory:

- H. Nyquist [5] demonstrated in 1924 that time can be regarded as a succession of discrete elements. His "sampling theorem" defines the minimum sampling rate necessary to obtain a complete reconstruction of a signal waveform from extracted samples. This Nyquist theorem is now one of the three pillars on which PCM systems theory rests [see Box A];
- R.V.L. Harley [6] pointed out in 1928 that information can be analysed in terms of the number of possible messages and that a measure of information can be based on a logarithmic scale of this number of messages. The idea of quantizing signal amplitudes can, again with hindsight, be glimpsed in his article.

1.4.4. While noting this convergence of the theoretical ideas of Nyquist, Harley and Shannon [2], which are very close to the theory of PCM systems, and noting in passing that the application of binary coding and the practical concept of the "bit" were developed by Shannon only in 1948, i.e. ten years after Reeves invented PCM, it has to be realized that it was practical laboratory work and experimental achievements, far more than theoretical considerations, which motivated the invention of PCM by Reeves.

2. Initial phase of PCM systems: birth of a novel concept

2.1. PCM was invented in Paris in 1938 at the research department of the Laboratoire Central de Télécommunications (LCT), an offshoot of the ITT Group, whose creation in 1927 had been a precondition for the establishment of ITT in France and for the choice of its Rotary system for the automatic network in Paris (see Volume I, pp. 195 and 263).

The LCT was set up to act, in parallel with another ITT research laboratory in London [3], as a modest counterweight in Europe to the part played by AT & T's Bell Laboratories in America.

Although in France (comfortably installed Avenue de Breteuil, one of the wealthier quarters of Paris), LCT worked exclusively for ITT. While it employed a number of French engineers, LCT

[2] C. Shannon, together with J.R. Pierce, B.M. Oliver, W.M. Goodall and R.W. Bennet, other leading minds at Bell Laboratories, was to play an active part in the basic studies on the theory of a PCM system eventually published in 1947 and 1948 [11].

[3] from 1978 onwards, this Laboratory was known as Standard Telephone Laboratories.

Box A
(for the layman)

The three "pillars" of PCM

1. Pulse code modulation, PCM, is a method for converting analog (speech) information into digital signals, where each signal is represented by a train of binary pulses. This conversion implies three stages, which we call the three "pillars" of the PCM principle:
- sampling
- quantizing
- encoding

a) *Sampling*:

If an analog signal is sampled at a given moment, an amplitude value is obtained which is called a "sample". If the sampling is carried out at regular intervals and at a rate that is sufficiently high in relation to the frequency of the analog signal, it is possible to reconstitute the analog signal from the sequency of samples. According to the Nyquist theorem, the sampling rate has to be greater than or equal to $2f$, f being the upper limit of the frequency band of the signal. For a speech band of 4 kHz, the sampling rate is therefore 8 kHz and the time interval between each sample is 125 microseconds.

b) *Quantizing*:

The different speech samples have varying amplitudes. Quantizing means that the amplitude range is divided into fixed sets of amplitude levels, the number of the quantized levels being dependent on the desired transmission quality.

c) *Encoding*:

Encoding means that the various quantized amplitude levels are converted in a number characterizing this level and expressed in binary values. The original analog (speech) sample is then represented by a train of binary pulses. In the international PCM standards, encoding uses 8 bits, which correspond to: 2 (power 8) = 256 quantized values of speech amplitudes. The bit rate of a PCM telephone channel is therefore:

$$8 \text{ kHz} \times 8\text{bit/s} = 64 \text{ kbit/s}$$

2. *Time Division Multiplexing (TDM)*

TDM is a technique in which message channels are interleaved in time for transmission over a common channel.

For each message channel of a CCITT primary PCM multiplex, there is a *time slot* during which the 8 bits coding the quantized level of a speech sample are transmitted. The set of the consecutive time slots allotted to each of the multiplexed message channels is *the frame*. The frame duration is equal to the interval between two sampling times for a message channel, and is therefore 125 microseconds (see 1.a above). There are 24 time slots per frame in the CCITT PCM "American" version and 32 in the "European" version.

was a fairly rare phenomenon in the inter-war period in that its international recruitment policy served as a melting pot for excellent engineers most of them very young and drawn from all nationalities: they included Belgians and Dutchmen from BTM in Antwerp, working on Rotary type [4] switching systems, Americans and Britons. The latter, mostly from ITT's British subsidiary Standard Telephone and Cables (STC), and highly appreciative of the pleasures of life in Paris, included Alec A. Reeves who, until the

[4] At least until 1930 when, as a result of the economic crisis, the ITT Switching Research Department had to leave Paris for BTM Antwerp (Volume I, p. 195).

German occupation in 1940, had spent more than 10 years there.

2.2. The telecommunications world started concerning itself with pulse modulation in the 1920s and an analysis conducted in 1940 [7] revealed some sixty patents relating to the subject. Those in the limelight included Rainey of Bell Laboratories who, in 1926, proposed for phototelegraphy to convert signals from digital to analog and vice-versa, and R.A. Heising of Western Electric who took out, in 1924 and 1925, two patents concerning a form of modulation offering uniform amplitude pulses of variable duration designed for use with radio systems. Most of the other patents [Belin (France), Marconi-Kell (Germany), etc., patents] concerned forms of modulation for providing pulses for producing the black and white spots needed for phototelegraphy and, after 1929, for television which was still in its early days [Telefunken (Germany), de France (France), etc., patents].

2.3. As was quickly discovered, pulse modulation required considerable bandwidths, a fact which seemed to make it prohibitive at the time. This obstacle was overcome by the introduction of UHF transmission with the first experiments [5)] in what were to become known as "beamed radio links", or later as "radio relay systems", thus paving the way for a whole series of investigations into pulse technology and eventually heralding radar. The chronology of the sixty or fifty pulse-modulation patents mentioned in [7] above shows a proliferation of patents from 1935 onwards, including French patent No. 652.163 of 3 October 1938, issued to Alec H. Reeves (LCT), which later was to carry so much weight:

"in order to avoid background noise in telephony, the waveform *amplitude range is divided* into bands of a finite number of values, *each amplitude* being transmitted as *a combination of pulse types*, this combination corresponding to predetermined values and selected on the basis of closeness to the amplitude value."

The three "pillars" of the PCM principle (see Box A above) are included in these prophetic few lines.

2.4. To the author's personal knowledge, no biography of A.H. Reeves has yet been published. The little that is known of him and his character is taken from a work by P. Young [1b] and from the memoires of his former colleagues. As a brilliant scholar at Imperial College, London, Reeves was a highly gifted eccentric. Perhaps we must thank his British genes, which seem to engender non-conformist youngsters brimming over with ideas, for certain similarities with his contemporary compatriot A.M. Turing or with such celebrated British predecessors as Lord Byron, his daughter (Lady Ada) and C. Babbage, the latter's mentor in the art of programming.

2.4.1. "A less than conventional radio engineer" [1b], an enthusiast and the owner of many patents, Reeves was an attentive observer of every phenomenon he came across. It was apparently he who, during the first microwave link experiment across the Channel, was first struck by the way the waves were reflected from the cliffs at Dover, recognizing therein the potentiality of a phenomenon which, a few years later, was to lead to the invention of radar.

2.4.2. Fascinated by electronics and a devotee of building "pyramids of electronic tubes" – a game to be considered as a forerunner of digital calculators and the first computers – Reeves was in fact living in two worlds at once, namely, the down-to-earth one of his job as an electronics research engineer and the esoteric one, of communicating with extra-terrestrials. He believed that on other planets, within or outside our solar system, there are also thinking beings, perhaps

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[5)] The first UHF link was established on 31 March 1931 over the Channel between France and England. Installed under the direction of M. Deloraine and A.C. Clavier of the LCT Laboratories, it was demonstrated jointly by LCT and its British partner, the STC. It was during the British press coverage of the event that a journalist coined the word "microwave" which has since become so widespread.

sufficiently developed to consider sending meaningful messages out into the universe. The LCT's night watchmen were thus used to seeing him arriving at night and climbing on to the terrace to gaze at the stars and meditate on the best way of detecting such messages. In this, too, he proved to be a visionary at a time when radioastronomy had yet to be accepted and nobody, not even science-fiction writers, had ever dreamt of launching intra- much less extra-planetary rockets marked with coded messages, as was the case with NASA's PIONEER rocket in 1984.

2.5. It is to be hoped that this account of an obviously highly romantic character will make up in human interest what it lacks in strict relevance to the arid technicalities of an otherwise somewhat austere book!. Indeed, it may even attract the curiosity of those epistemologists who are forever seeking to discover the profound motivations, sometimes tinged with ethical, philosophical or even religious conceptions, of those now regarded as scientific or technological innovators. It is undeniable that Reeves's exalted vision of his field of study, with its leaning towards the extraterrestrials, must have encouraged the tendency of his superiors to look upon his ideas as extravagant flights of fancy.

2.6. The account of how the Reeves patent was taken out in France in October 1938 also has an anecdotal flavour about it and it is indicative of the more or less masked migivings that the ITT management may have harboured regarding the products of his imagination. Disregarding the strict rules of the London Patent department of the ITT requiring prior permission to taking out patents in Europe, L. Cherau, its correspondent for LCT, acting on his own initiative and without authorization, checked whether any earlier claims had been lodged and, realizing the potential interest of PCM applications and enthusiastic about the novel principle involved, took out the patent in Reeves' name on behalf of LCT.

2.7. The patent might, like so many others, have passed unnoticed and passed into oblivion. Reeves himself took no further interest in it. Having escaped from France to England in June 1940 during the German invasion, he was assigned to the Military Laboratory at Malvern for research into a project for guiding bombers to their targets, a task which completely absorbed him. "Having had PCM patented, for understandable reasons, I then let the invention slip from my mind until the end of the war" [8]. It was in the United States during World War II that the next step in PCM's progress was made, by the Bell Telephone Laboratories.

3. Second phase in the birth of PCM systems: studies by Bell Laboratories into a telephone system affording absolute secrecy for military purposes

3.1. It is in the volume of Bell Laboratories's entitled "National Service in War and Peace" [9] that we again pick up the main thread of our narrative, one which may be termed the "saga" of the birth of the PCM system.

In October 1940, even before the United States entered the war, Bell Laboratories had been asked by the Department of Defense to develop a telephone transmission system affording absolute secrecy for long-distance radiocommunications. Based on the VOCODER systems developed in the early 1930s for transatlantic radiotelephony, but also including sophisticated cryptographic devices, the top-secret study of what was simply code-named the "X system" mobilized an entire group of Bell Laboratories' most distinguished engineers. Most of the names quoted in [9] in this connection had already achieved world renown or did so later.

3.2. It was only in mid-1943, when the first equipment of the "X system" was produced and studies were continuing into an improved version, that the group of Bell Laboratories engineers learned of Reeves' patent and realized its true value.

The studies into the "X system" were treated as a top military secret and were declassified only in 1975. The list of patents associated with these

investigations is extremely long (see [9]). After discussion in internal memoranda within Bell Laboratories, scientific studies of the theory behind the PCM concept, this time in connection with civilian applications, gave rise to a whole welter of publications in issues of the BSTJ from 1947 to 1949, including:

- W.M. Goodall's "Telephony by Pulse Code Modulation, July 1947 [10], and
- C. Shannon's famous "A Mathematical Theory of Communication", July 1948 [4] and of a Bell System Monography, "The Philosophy of PCM", November 1948 [11].

4. Third phase: PCM systems find their first field of applications: the junction circuit network for local services

4.1. The first PCM systems for civilian purposes were produced by Bell Laboratories as a result of the theoretical studies mentioned in section 3 above; this occurred in the early 1960s and was the subject of publications in 1962, e.g. [12].

These achievements were made possible through advances in electronics: the PCM terminal equipment designed by Bell Laboratories used only solid-state components.

Thus was born the American "T1 carrier" PCM system. The definition of the essential parameters of the system, particularly its 24 channels (the "digroup") per system, was to serve as a modular basis on which an entire family of systems derived from the initial T1 system was to be established and used throughout North America [6]. With some modifications and enhancements and the establishment of an entire higher-order multiplexing hierarchy, the denomination *T* was retained for more than 20 years for the entire family of systems, and is indicative of the continuity of approach that lays behind all these digital systems.

4.2. The T1 system was designed in the late 1950s and early 1960s [7] to meet the Bell System's need for a carrier system that was both economical for distances up to about 25 miles (40 km) and could operate over the existing pairs of cable junction networks.

Because of its economic viability, the T1 system [8] spread like wildfire within Bell System's network and, by 1965, 100,000 telephone channels were already using PCM systems. The keen interest shown in the T1 system was motivated by the high cost (including civil engineering work) of laying new urban cables and the saturation of the junction line networks at a time when there was a problem of meeting a considerable increase in the number of subscribers and a heavy traffic demand.

4.3. The saturation of junction line networks was by no means peculiar to the United States: the first half of the 1960s marked a period of telephone expansion in every industrialized country. On the other hand, the transistor and the first integrated circuits had become available and their technology had been fully mastered.

In the wake of the United States and its Bell Laboratories, studies on PCM systems flourished from 1965 onwards in Japan, from 1966 in the United Kingdom and in many other countries between 1967 and 1970.

The studies varied widely [9], being differentiated by the number of channels envisaged for the primary multiplex equipment, the coding law and research into procedures which, although digital, offered a greater bandwidth economy than the PCM properly so called (e.g. the "delta" modulation system, proposed in the Netherlands by de Jager [14]).

[6] Systems T1, T1C, T1D, T2, T4, etc.

[7] Development of a PCM Time Division Multiplex carrier was authorized in Bell Laboratories in 1955 [13].

[8] The first installation of a production T1 system as a junction route occurred in the Chicago local network in 1962 [12].

[9] Except in Japan where the Japanese PCM system was to be virtually modelled on the standards laid down for the "TI" American system.

5. Fourth phase: PCM systems for long-distance circuits and the need for PCM international standards

5.1. From 1968 onwards, there was evidence of a desire in Japan, the United States and various other countries to use PCM systems for purposes other than purely local junction networks. Such systems were required for use not only over twisted cable pairs initially intended for audio-frequency transmission, but also over coaxial cable pairs and after 1970, over radio relay routes [10]. This time, they were to be used for long-distance circuits and a whole multiplex equipment hierarchy was envisaged.

5.2. PCM systems had to be internationally standardized when it became likely that they would find their place in international network routes. Incidentally, outside the United States, such standardization was bound to receive a welcome by the telecommunication equipment manufacturing industry. Even more than the bodies operating public networks, industrialists were anxious to have a little order restored in a situation they found chaotic: divergent moves had been the order of the day and, with their export markets spread over many countries, they were eager to discover on which standards their PCM equipment should be based.

6. CCITT standardization for PCM systems

6.1. The standardization of PCM systems by the CCITT has been a long and laborious task.

It required painstaking in-depth studies to agree on the basic parameters of an international PCM system – the number of coding bits, non-linear quantization characteristics, etc. The aim was to secure, in an international service liable to involve a multiplicity of PCM systems in tandem, a transmission quality equal to or better than that obtained with analog systems [15].

As a result of those studies and after arduous discussions during two CCITT four-year study periods, the Vth Plenary Assembly in 1972 [11] came up with a solution, such as it is: it can scarcely be regarded as a model of its kind and has even been described as a semi-failure on the part of the CCITT, because two different, parallel, sets of standards had to be defined.

Specialists in PCM refer to each of the standards applicable to one or the other of the systems by numbers of the CCITT series "G" Recommendations [12] which carefully set out all the details of their specifications. In ordinary language, they are differentiated by the number of telephone channels provided by their primary multiplex and/or their initial field of application as follows:

- the so-called North American system (also used in Japan), characterized by a primary multiplex of 24 telephone channels;
- the so-called European system, used in the rest of the world, characterized by a primary multiplex of 32 channels (providing 30 telephone channels).

6.2. Points common to both types of system: they each use 8 bits for coding the amplitude of an audio signal sample [13]. The sampling frequency also is the same in both systems, namely 8 kHz, which corresponds to the application of the Nyquist rule (sampling frequency equal to double the frequency defining the transmitted frequency band) to the 4 kHz frequency band defined as the standard spacing between telephone channels in the CCITT primary ana-

[10] The first radio relay link for digital transmissions in the United States network was installed by NEC in 1972 between Brooklyn and North Staten Island in New York.

[11] Following a study on PCM systems already launched by the IInd CCITT Plenary Assembly (New Delhi, 1960) and allotted to Study Group XV (Telephone Transmission), a Special Study Group, "Special D", was set up by the IVth Plenary Assembly (Mar del Plata, 1968) to investigate in depth PCM systems.

[12] The Fascicle III-3 of the CCITT Book

[13] At least in the American version for PCM systems designed for international service, a change from the initial versions of T systems which were based on $7\frac{5}{6}$ digits.

log multiplex system (12-channel group at 60–108 kHz).

6.3. Apart from various other subtleties on which we shall not dwell here but which include the placing of the bits used in each system for:
- signaling over a particular telephone channel;
- the frame alignment of a 24- or 32- channel primary multiplex,

the two PCM systems standardized by the CCITT differ in two fundamental characteristics. These are the number of channels provided by a primary digital multiplex (24 or 32, as mentioned earlier) and the μ or A parameters which define the companding law used for coding in such systems.

We shall briefly mention here the considerations which led to the option peculiar to the two systems standardized by the CCITT

6.3.1. The 24-telephone channel T systems adopted in North America from 1962 were already in operation in the United States and had been very widely installed in the Bell System network and in the "Independent" companies networks. It was this *de facto* situation which led to the retention of the 24-channel standard for primary PCM multiplexing on that continent.

In Europe, on the other hand – except in the United Kingdom where 24-channel PCM systems were already common (7000 in 1978) [17], only a few PCM systems had been brought into service, some using 24 channels and others, as in France, 36. Studies conducted among European Administration in the CEPT and, later, taken up by the CCITT revealed the advantage of a 32-channel primary multiplex system. One particular reason in favour of the choice of this key value: it belonged to the "magic numbers" series expressed in powers of 2 (32 = 2 to the power 5), a value which was appropriate for defining an entire higher-order multiplex hierarchy, as shown in the following table which corresponds to the CCITT specifications now in force for the "European" PCM version (Table 1).

Table 1

Digital multiplex	Telephone channels	Comments
primary	30 *	
		each higher-order multiplex
secondary (2nd order)	120	connects four lower-order
tertiary (3rd order)	480	multiplexes

* Note: In the 32-channel multiplex, two channels are not used for telephone speech path. They are reserved, one (channel 0) for frame alignment signals, and the other (channel 16) for the signaling of each of the 30 telephone channels of the mutiplex

6.3.2. The coding laws of the "North American" and "European" PCM systems differ. In accordance with a theory well-known since the first extensive studies of PCM systems in 1945–1947, the purpose of a coding law is to minimize the "quantizing distortion":
- by decreasing the quantum step size at low levels of speech power;
- by increasing it at high levels.

This involves a logarithmic compression of the type, $Y = \log X$, where the quantizing levels are close together near the origin and farther apart at peak values of X. Compression is intended to minimize the dynamic range (of the order of 40 dB) of the speech powers encountered on a circuit, which may vary with the speakers and with the type and number of circuits in the connection chain.

The "American" coding law is known as the μ law, where μ (a Greek letter) is the conventional parameter characterizing the companding systems that have been used for many years for certain analog connections, e.g. over transatlantic radio circuits. Originally set at the simple value of 100, the parameter μ was defined as being equal to 255, following refinements which strict requirements of transmission quality were to impose on international PCM systems during the many decades to come.

The "European" coding law is known as the A law. The parameter A defines the range of values near the origin:

$$\frac{x}{x_m} < \frac{1}{A}$$

for which the interpolation of coding values is linear before it becomes logarithmic at higher values. Initially set at 100 during preliminary studies, the A value used in the European coding law was reduced to 87.6 for the same reasons as those for which, as explained above, the value of μ used in the

American coding law was increased from 100 to 255. The values $A = 87.6$ and $\mu = 255$ may seem somewhat disconcerting for the engineer but, in fact, they are the result of numerous calculations and equally laborious discussions in the CCITT. Moreover, their mention has since dissapeared in CCITT Recommendations, which now simply give the coding tables for:

- the 15 ranges of values (positive and negative) corresponding to a given coding under the μ law ("American" version);
- the 13 corresponding ranges of the A law ("European" version).

6.3.3. As we have seen, the μ law originated in the United States and was defined as long ago as 1962 [17]. The A law was the result of studies conducted by the research departments of the British Post Office. When the European PCM system was being defined, the other European countries tended to support the British A law. The United Kingdom, far in advance of its European partners in having introduced numerous 24-channel PCM systems, agreed on its side to a standardization based on a 32-channel primary multiplex.

6.4. The above is but a pale reflection of all the studies that were needed to specify the PCM systems standardized by the CCITT. The specifications alone fill close to 200 pages of the CCITT Book, in Fascicle III-3 (Recommendations G.701-G.956) which contains no explanation of the many reasons which led to this or that choice and is simply a dry enumeration of all the clauses relating to the two systems. Among those clauses, many of which are almost as fundamental as the ones briefly described above, we shall simply mention those relating to:

- the performance parameters required of a voice-frequency PCM channel;
- the frame and multiframe structures, the frame alignment strategies;
- the allotment of bits for signaling (channel associated and common channel signaling);
- synchronization devices and their performance;
- all the precautions required agains jitter, etc.

7. PCM systems, the "building blocks" for a digitized telephone network

7.1. A PCM system, with its simple reference characteristics:

- 64 kbit/s;
- 2 Mbit/s and 1.5 Mbit/s (abbreviated denominations of the bit rates of the "European" and "North American" primary multiplexes, which are in fact 2048 kbits/s and 1544 kbit/s),

is regarded by the engineer of the 1980s as a reality familiar to everyone in the profession and a standard product requiring no further explanation.

7.2. Indeed, PCM systems have become the basic modular component, the "block" as it were from which is built the vast complex of an "integrated digital network", the IDN, incorporating both transmission and switching, which will occupy us through the 1980s and perhaps, in its ISDN (Integrated Service Digital Network) versions, even through the 1990s.

It is the importance of PCM systems in the telephone network digitization process which justifies, if justification is needed, the inclusion in this switching-oriented book of an account of all the technological development which, for the most part, we have to recognise that we owe to the "transmission engineers", although they frequently had to consult their colleagues in the switching and especially in the signaling fields.

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CHAPTER VIII-2

THE BIRTH OF DIGITAL SWITCHING

1. The switching network of a digital exchange and its basic components

1.1. It is often difficult for anybody without a background in modern switching engineering to grasp the concepts of digital switching, those briefly covered in section 3 of Chapter I-3. Now that we are about to describe the long lead-up to the formulation of the concepts which govern the architecture of switching networks at digital exchanges, it might be useful to recall them in Box A.

The description in Box A is essentially of a didactic nature. For the most part it is based on the text of a paper delivered by M. Hoshi to the ITU Switching Seminar in Singapore in 1978 and reproduced in a special switching issue of the Telecommunication Journal [1] published on the occasion of the Paris ISS in 1979.

We say that the description is didactic because, in digital exchanges, the switching network fabric may come in a wide variety of architectures: indeed, the T and S elements described in Box A, which serve to constitute the stages of the network, may be distributed in different configurations, the order of the stages being a designer's choice:

- in a T-S-T sequence, the commonest arrangement in exchanges being built in the late 1980s;
- of the S-T-S type;
  (In general, it has been found that smaller systems may better employ S-T-S networks, where large systems use T-S-T.)
- with several S stages between an incoming T stage and an outgoing T stage, as in the case of large or very large capacity exchanges;
- or with only one T stage, as in very small capacity exchanges;
- or with only one S stage.

In addition, there has been an assortment of other configurations which, although rare, have nonetheless existed.

It will also be noted that the description given refers in the case of both the T stage and the S stage to a control organ (called the "control memory" in the text of Box A) specific to each stage. Here again, our approach is a didactic one, tending to an exposition simplicity and because that was the first arrangement used. Nowadays, however, the T and S stages are as a rule no longer controlled by specifically related organs but by the processor or processors which control the exchange (or the switching network) as a whole.

1.2. Digital Time-Division Switching Networks

1.2.1. Thus, time-division switching networks in digital exchanges are made up of combinations of T and S stages.

The time-division digital network is actually a "dual" network consisting of two parallel networks controlled by a single network control circuit (memory). Each of these networks corresponds to one direction of transmission for a PCM channel. The topology of each of the two parallel networks is a two-sided one, with incoming transmission lines appearing on one side while outgoing lines appear on the other. Interconnect-

Box A

Description of the basic building blocks of a typical digital time-division exchange (from [1])

1. The switching network performs switching between time-multiplexes buses. To allow connection between different time-slots in different buses, both switching in time and space are generally necessary for a switching network of rather large traffic capacity.

2. A "time-switching" stage (the so-called "T" stage) consists of an incoming *speech memory*, where PCM words will be delayed an arbitrary number of time-slots (less than one frame). The writing of the information of incoming time-slots into the cells of the incoming speech memory is normally sequential, and each cell receives one 8-bit word of the PCM incoming channel. The reading of the incoming speech memory will be controlled by a *control memory* associated with the "time-switching stage" ("T" stage). This control memory orders the reading of a specific cell in the incoming speech memory after a "Time Slot Interchange" delay. The effective delay is obviously the time difference between the writing into the speech memory and the reading out of the memory. According to the arrangement of the "T" stage, the transfer of the 8-bit word of a PCM channel from the incoming speech memory can take place either to an "outgoing speech memory" or to an outgoing PCM bus. In the first case, this transfer is generally performed not serially but in parallel through eight wires connecting the incoming and outgoing speech memories. Such an arrangement offers a greater speed of switching (for the layperson's readership, it should be noted that on PCM transmission lines the digital signals travel only serially along the line).

3. A "space-switching" stage (the so-called "S" stage) consists of a *crosspoint matrix*, $n \times n$, where the individual crosspoints consist of *electronic gates* [1)]. To each crosspoint column is assigned a cell of the control memory associated to the "S" stage, which has as many words, F, as there are time-slots. Typical figures for F are, e.g., from 32 up to 1024. During each individual time-slot the crosspoint matrix works as a normal, space-divided matrix with full availability between incoming and outgoing buses, the crosspoints being controlled by certain cells in the control memory. Just as a time-slot shifts to another, the control memory is advanced one step and during the new time-slot a completely different set of crosspoints is activated. This goes on in cycles of F steps. This time-divided behaviour increases the utilization of crosspoints in the order of $F = 32$ to 1024 times as compared to a normal space-divided switching.

Remark. On thinking it over, we may note with Hoshi that there is some paradox in the classical terminology described above and now so firmly coined, since it can be observed that:
- the "time-switching stage" T does not work in a time-divided mode: in the incoming and outgoing speech memories the same cells are used exclusively for a certain call during the whole connection;
- the "space-switching stage" S, on the other hand, works completely in a time-division mode.

[1)] The action in a "S" stage is sometimes called, especially in American terminology, "Time Multiplexing Switching" or "TMS". In TMS, a number of frame-synchronized digital channels are connected as required to pass information in the same time-slot from one channel to another.

ing the receiving end of one line with the transmitting end of another line is only half of the connection. To connect the other half, a reciprocal relationship is established within the parallel network so that the connection in the inverse direction may be established.

Buffering of lines to provide frame synchronism of all time slots entering the switch takes

place at the digital line interface circuit between the transmission system and the switching system [2].

Since time-division networks employ many active elements, it is not unusual for these networks to include redundancy similar to that designed into the control portions of the system. This redundancy is in addition to that required for the reciprocal relationship. Also, within a switch, additional bits may be added to the sample for such functions as parity checking, signaling, or other functions.

1.2.2. Integrated circuit chips are now available that combine S and T functions so that, especially for RSUs (Remote Switching Units) and typically, eight incoming 32- (or 24-) channel lines may be connected to eight outgoing lines, thereby switching as many as 256 (or 192) time slots on a single chip, sometimes in both directions.

1.2.3. To sum up, time-division switching networks use combinations of time slot interchange ("T" stage) and time multiplex switching ("S" stage) elements to associate time slots for transmitting and receiving between different digital transmission lines.

1.3. After all these technical explanations on the architecture of digital time-division switches, let us now address ourselves to historical matters and describe the long gestation period which eventually led to the birth of digital switching. This spanned the years from 1945 to the early 1960s, i.e.:

- from the *first time-switching devices* using the time displacement of pulses, although these were of a non-digital type and had pulse amplitude modulation (PAM) (section 2 below);
- via the introduction of *digital transmission* with pulse code modulated (PCM) multiplexing as described in the preceding Chapter;
- to the emergence of *digital switching* in the 1960s (section 3 below) when its basic concepts were worked out and formulated (section 4 below).

[2] This circuit may also provide for the conversion from serial to parallel and the addition of bits.

2. The birth of the ideas of time-division switching with time-slot interchange [2]

2.1. As we have seen in Chapter II-3, section 3, in 1945 it became clear to Deloraine (see Box B) that, for switching, the time slot of one channel within a group of time-division channels could be displaced to correspond to the time slot of another channel, thereby establishing their connection. This principle was covered by an application for an U.S. patent under the title "Pulse Delay Communication System", filed on 14 November 1945 [3]. The basic character of this invention appears from the claims granted under U.S. patent No. 2,584,987, delivered on 12 February 1952 after a very long examination of no less than 7 years. However, this delay between the first filing of the invention in USA and the granting of the patent was without effect on the dissemination of the proposal. As early as 18 August 1947, a French patent No. 930,641 had been issued.

This was "switching by pulse displacement", the very principle of what is called today "Time Slot Interchange". The implementation described in the patent provided delay lines, adjustable according to the code of the called line. That is now what is called a T element in a "TST" (Time-Space-Time) switching structure.

Switching by the time displacement of pulses in a group of channels was presented by Deloraine at the IRE Convention (Institute of Radio Engineers) in New York in March 1947. His lecture [4] mentioned the possibility of using this technique to associate the fields of transmission and switching, so far separated, into an integrated network.

Eager to highlight the importance and originality of his invention, Deloraine presented it on 21 March 1949 in the form of a doctoral thesis at the Sorbonne where it received the highest honours.

Box B

The personality of M. Deloraine

Over an extremely long and brilliant career, Maurice Deloraine spent more than 50 years (1918–1975) familiarizing himself one after another with all aspects of telecommunications, which until the 1980s were highly self-contained. The confluence of skills in the then separate fields of radiocommunication, transmission and switching provided him with a source of novel ideas and patents which made him an outstanding pioneer of our present-day telecommunication technology.

In 1917, Deloraine was called to the colours almost immediately after joining the "Ecole supérieure d'Ingénieurs de Physique et Chimie" in Paris at the age of nineteen. After serving at the front in the Signals corps, operating the first radio sets fitted with electronic tubes, he was posted to radiotelegraphy operations at the Eiffel Tower under General Ferrié, the grand master of inter-allied telecommunications. Upon the young engineer's demobilization, the appreciative Ferrié recommended him to Frank Gill, the London manager of International Western Electric. So Deloraine left for England where he grappled with the mysteries of telephone transmission and assisted in the design of Western Electric's first European long-distance cables.

After telephone transmission, back to radiocommunications. While still with Western Electric in England, Deloraine helped to create the first transatlantic radiotelephone circuit, the one between London and New York and using long waves (56 kHz).

Following the formation by Sosthenes Behn of the ITT Group and ITT's takeover of Western Electric's European companies in 1925, Behn recalled Deloraine to Paris to coordinate the group at the technical level.

In 1927 Deloraine was given a new assignment and a change in technical direction, this time towards telephone switching. Against stiff competition, ITT had sold its Rotary system to the French Administration for the automatic telephone network in Paris [1 of Box B], and its agreement with the French Government provided for the establishment of an ITT research laboratory in the capital. At the age of thirty, Deloraine was appointed manager of the laboratory which was set up in the elegant avenue de Breteuil in the heart of the city. After several changes of name, the laboratory was eventually to become known as the Laboratoire Central de Télécommunications or, better and more simply, by its acronym "LCT".

Within a short time the laboratory had a staff of several hundreds and was the first such international research centre to engage in international recruitment. Thus Deloraine was able to call on the skills of the cream of the research engineers working for companies within the ITT Group, most of them drawn from the Bell Telephone Manufacturing Company (BTM) in Antwerp and Standard Telephone and Cables (STC) of London, the latter team included Alec Reeves. When LCT and Le Matériel Téléphonique (LMT) set about installing Paris's first electromechanical Rotary exchanges, Deloraine soon learned just how complex, and often confusing, switching technology can be [2 of Box B].

Under Deloraine's prodding, LCT's activities turned increasingly towards radiocommunications, particularly those using very short waves. Notable events in this field were the introduction in 1931 of the first-in-the-world microwave link, the one between France and England and using parabolic dishes (indeed, the term "microwave" was then coined by English journalists covering the event), later the first multiplex radiotelephone link (1939), and both military and naval (instantaneous direction finding, navigational radar, etc.) applications. In related studies LCT also achieved major developments in pulse modulation techniques; indeed, by 1938 Reeves had filed for LCT his famous patent relating to pulse code modulation (PCM).

Towards the end of 1940, Deloraine and three LCT engineers (including Busignies who had invented a naval direction-finder offering instantaneous reading) managed to escape German-occupied Paris and get to the United States via North Africa and Portugal, taking with them plans of the latest military devices developed by LCT. Busignies' direction-finder, which thereafter became known as the high-frequency direction-finder and was dubbed "Huff Duff", was immediately adopted by the US Navy and, when mass produced, was to play a forefront role in detecting enemy submarines in the Atlantic.

Box B (continued)

In 1945, after spending the war years travelling the United States in connection with the development of equipment for the US Department of Defense, Deloraine was struck during an overnight rail journey between New York and Chicago by the novel idea that the extremely short pulses of a high-frequency series might be steerable through gates to this or that output channel. Thus the idea of time-division switching was born. With the help of D.H. Ransom, an engineer with Federal Telephone and Radio (FTR – the company which carried on ITT activities in the United States during the war years), two original patents [3 of Box B] relating to such switching were filed in 1945.

Once the war was over, Deloraine resumed his post as Technical Manager of ITT. He enjoyed President Behn's absolute confidence and his professionalism earned him, in particular, decisive influence over the selection of what were essentially the switching systems being industrially marketed by the ITT Group, i.e. the Pentaconta crossbar system in the 1950s and options which eventually led to the SPC Metaconta system. It was under his guidance that the different time-division switching ITT prototypes subsequently came into being, initially in analog versions but from 1960 onwards in the form of digitally switched models.

Business management is not immutable, however, and for ITT, it became not so much a matter of promoting research and development in order to be a leader in technological progress as of stopping at nothing to ensure the financial expansion of the Group which, by the 1960s, had become a highly diversified conglomerate. The role of ITT pioneer in time-division and digital switching, a privilege derived from research within the ITT Group, began to fade at about the time when Deloraine relinquished his post of Technical Director at the age of retirement. Perhaps this explains the highly symbolic and somewhat nostalgic way in which he gave the English version of his memoirs the title "When Telecom and ITT were young" [2 of Box B].

Bibliography of Box B

[1] The battle for the automation of the Paris network, "Box C" in Volume I, page 198.
[2] M. Deloraine, Des Ondes et des Hommes. Flammarion, Paris, 1974, pp. 72–85; English version: When Telecom and ITT were young.
[3] US patents 2.492.344 and 2.584.987, filed in 1945.

2.2. Under the direction of Deloraine, then ITT Technical Director, the importance of the field thus opened retained the attention of the research departments of ITT associated companies in Belgium, France and the United Kingdom. Between 1947 and 1960, a number of patents on time-division switching, covering variations of and improvements to the original Deloraine patent, were filed by these research laboratories. All these patents were granted without problems, except in the United Kingdom where one of those filed by the British ITT Company "Standard Telephone and Cables Ltd" (STC) was opposed by the "British Telecommunication Research Ltd.". After examination of their scope, all claims to this patent were finally granted to STC [3].

In September 1951, an LCT model (a mock-up model, ITT coded as "A") was a first step in establishing the validity of hopes placed in time-division switching. The model was based on the principle of a time-division multiplex highway connected to the subscriber lines by electronic gates handling PAM pulses [5]. In the mid-1950s, the laboratories of Bell Telephone Manufactur-

[3] One of the experts designated was T.H. Flowers of the General Post Office Research Department, who later, in 1957, wrote qualifying the Deloraine thesis at the Sorbonne as "a historical document".

ing Co. (BTM) in Antwerp started another development of the same type aimed at the design of a full size exchange, and using only solid-state components. A description of this model was presented in the London 1960 ISS by H.H. Adelaar, F.A. Clemens, J. Masure and published in [6].

3. Time-division switching no longer with PAM pulses, but with PCM speech samples

3.1. The early 1960s are marked by the appearance of the first efficient solid state components and memories. They are the ones that enabled Bell Laboratories to implement the Pulse Code Modulation ("PCM") principle for use as digital multiplexes on short-haul interoffice trunks of the Bell Operating Companies. It was the birth of the 24-channel – or digroup – "T1" multiplex [4] which was to become the American standard in digital transmission. In 1959 when the technical and commercial success of digital transmission lines was about assured, it was also, always in the Bell Laboratories, the first system proposal specifically exploring the switching of digital signals with ESSEX [7,8], the first experiment on integrated digital switching and transmission (see Chapter II-4, section 1). ESSEX's mission was to show how the switching function might be performed without returning each conversation path to baseband (analog) transmission.

As ESSEX was described publically, it captured the imagination of switching engineers the world over. It has been said that the publications describing ESSEX were the most attributed references ever encountered in the switching field. Throughout the world administrations rushed to set up studies on the principles demonstrated in ESSEX.

3.2. In 1958, the same technological progress in components as those used for the PCM transmission lines and the ESSEX experimental model allowed the ITT Laboratories, and more specifically LCT in Paris, to file a patent [9] on the principle of time-slot displacement of PCM speech pulses to obtain time-division switching models. The feasibility of the Deloraine idea, which originated in its principle in 1945, was demonstrated practically in 1962 [10] with an exchange model dsigned for military networks.

In the case of both PCM transmission systems (from the 1938 Reeves patent to the introduction in 1962 of the "T1" PCM system by AT&T) and digital time-division switching systems (from the 1945 Deloraine patent to the early-1960s developments), it took about 20 years for their principles to be implemented. The wide acceptance of these techniques occurred only after the spectacular evolution of integrated solid-state devices, of logic circuitry, and of the steadily increasing storage capacity of memories.

In the early 1980s the emergence of microprocessors allowing an economic decentralization of control functions, the evolution of digital transmission systems (wide-band radio links, optical fiber cables) turned out a success with massive industrial implementation of the two associated techniques of PCM transmission and digital time-division switching, and gave rise to the beginnings of the ISDN (see Chapter X-9).

3.3. The credit for having first produced a PCM switch with solid-state devices, associated with concentrators and multiplex PCM trunks, unquestionably goes to Bell Laboratories with their ESSEX experimental model. To the Laboratoire Central de Télécommunications should go the credit for having been the first to show how to combine PCM transmission with switching by time displacement of coded pulses and permit the practical integration of transmission and switching by introducing memories into the switch. In these memories the signals belonging to an incoming channel were stored until they could travel across the switch and leave it for an outgoing channel, at a time different from their time of arrival.

More specifically, it is the appearance of digital memories able to store the PCM coded speech

[4] The "T1" transmission multiplex was subsequently renamed and is also now referred to as the "D1" system.

samples in what was to become known as a "T" stage of the switch which marked the implementation of the basic Deloraine concepts. These memories had two associated purposes:

a) to solve the problems arising from imperfect clock synchronization between various exchanges, as well as from propagation time variations on the PCM circuits (what is called "frame alignment");
b) to introduce a delay between the times of arrival (writing a speech sample) and of treatment in the switch (reading the sample) of the signals related with an incoming voice channel so as to permit switching between incoming and outgoing channels occupying different time slots.

These memories have the same function as the delay lines of the 1945 Deloraine patent. An essential factor of what PCM has brought into the design of the time-division switch was to get rid of the crosstalk due to crosspoints in the gate-switching bus-matrix of the systems switching PAM pulses. In these systems crosstalk was important [5)] and none of them succeeded to reach the industrial stage in public switching.

3.4. Thus, in the late 1950s, LCT submitted a proposal to the French army for a time-division digital (PCM) switching equipment. When compared to the traditional technology of electromechanical switching with moving parts, the advantages of switching exchanges using only solid-state components are evident for military networks. Moreover such networks offer specific features which at the time facilitated the introduction of the new technology proposed:

- they are closed networks, sometimes of very limited range;
- the telephone sets accessing the switches can be of a special type; in particular, they can be provided with a 4-wire access to the switch;
- and, another aspect of a very different nature but which might have had its importance at the time, defence budgets generally offer good prospects for research contracts.

The French Signal Corps officers had early realized all the technical advantages and capabilities of the LCT proposal. The military network they had in mind at this time was to comprise nodal switches to handle the traffic of 12 PCM multiplexes of 24 channels each, associated with concentrators connecting 50 telephone sets to one PCM 24-channel link [2,10]. After a first presentation in 1962 of a mock-up model, various prototypes were developed until 1968.

The system which had received the name of RITA (Réseau Intégré de Transmission Automatique) has in itself a long history. After many improvements, mainly in its software, had been introduced to meet all the very specific and intricate military requirements for tactical use in the battlefield, it was standardized in 1971. After long field tests on army manoeuvres it became the French army system in 1979. Later, in 1985, after severe competition it was also adopted as the tactical communication system for the U.S. Army.

4. Forging of digital time-switching concepts and terminology in the early 1960s. The "deliverers"

4.1. It was in the early 1960s that the basic concepts which would thereafter govern the terminology of digital time-switching were forged in such a way that they became perfectly clear to engineers.

Following the conception by Deloraine, Flowers and others of novel ideas concerning time-division switching between 1945 and 1955, and after the development by Bell Laboratories of PCM digital multiplexing in 1955–1958, the ensuing years witnessed what might genuinely be termed the birth of the first offspring of digital

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[5)] In time-division switching of the sort using PAM pulses, one imperative requirement of the crosspoint (a "gate") is that it quickly forgets the information it has just transmitted so as not to disturb the following information; in other words, to prevent crosstalk. This meant that all transistors used as gates in a PAM system should have switched more extremely steep-edge pulses than they actually did.

Fig. 1. Professor H. Inose

switching and the honour of having delivered them must go to:

1) H. Inose (University of Tokyo) (Fig. 1) who in 1961 [11] fathered the eminently expressive formulation of "Time Slot Interchange". A specialist in traffic studies relating to switching network design, he also introduced the both demonstrative and efficient conceptual method for transposing a time-switching network structure into a space-switching structure, in a mode of conversion by analogy. Everything that had been learned from several decades of research for optimizing space-switching networks (the "link system", the "CLOS" network structure [12], etc.) thus suddenly became applicable and offered an extremely helpful tool for use by time-switching system designers.
2) E. Touraton and J.P. Le Corre (both of LCT, Paris). Following up their patent of 1958 [9], in 1963 they published in conjunction with other LCT engineers [13] a description of what they called a "T stage" and an "S stage"; these two denominations have since remained unchanged and have become the conventional terms used in every description of digital switching systems and their switching networks.

4.2. *Inose's innovations*

We have already seen the impact which Bell Laboratories' production of the ESSEX combined PCM-multiplex switching and transmission network had on the telecommunications world and the interest aroused by relevant articles in the Bell System Technical Journal [7] and papers delivered at the London ISS in 1960 [14].

However, switching engineers were left somewhat in the air as to the workings of the exchange's switching network at which the PCM multiplexes terminated [6]. In fact the ESSEX switching network consisted of two types of time-division buses:

- those providing a PCM multiplex access to the exchange;
- and "junctors" which, by means of gates which the exchange's control opened at a given instant, connected an incoming PCM bus to an an outgoing one.

In short, this arrangement duplicated – albeit this time using PCM buses – the one which previously used PAM pulses in the time-division exchanges being researched at the time, models such as Britain's experimental Highgate Wood exchange. Thus, the ESSEX system included the solution to only one part of the digital switching

[6] The construction and demonstration of the ESSEX model was not regarded as an outstanding event in switching history even though it did trigger many initiatives and much research into time-division switching. Its chief impact was that it opened up broad avenues of research for incorporating digital transmission and switching within a single network.

In this respect it is is significant that those responsible for documenting major events at Bell Laboratories in the " History of Engineering and Science in the Bell System" collection saw fit to describe the ESSEX experiment not in the Volume devoted to switching [15], but in the far more general Volume entitled "Communication Science" [16].

problem, switching between one digital line and another. This meant that the system had a high blocking loss since it was necessary to assign the originating and terminating lines to the same time slot. Moreover, each line entering a digital switching office had to be buffered so that the internal clock of the system could cause all frames of time slots to enter the office in time step or synchronism.

As Inose explained in [17], "even if a sufficient number of junctors were provided in the switching network of the ESSEX exchange, 'time-slot mismatch' in the three (or two) time-division buses (the incoming bus, a junctor bus, the outgoing bus) to be connected was the dominant factor causing internal blocking. The restriction of using a commonly idle time-slot was to be removed by providing appropriate delay devices into the junctors". This was the subject of a famous US patent filed by Bell Laboratories in the names of H. Inose, while he was there on leave from University of Tokyo, and J.P. Runyon [18] in 1960.

The concepts of "time-slot interchange" and of transposing a time-division structure of switching network into a space-division structure were eventually published by Inose in collaboration with other Japanese researchers in [19] in 1963 and at the 1966 Paris ISS [20].

4.3. *Achievements of Touraton and Le Corre*

Five years after these two had filed their patent in 1958 [9], J.P. Le Corre published in 1963 an extremely clear article [13] on the architecture of their digitally-switched RITA exchange; this contained a precise description of what he called:

- the time-switching stage (the "T" stage), and
- the space-switching stage (the "S" stage).

These terms eventually prevailed after a period of competition with equally valid rivals [7]:

- M (for "memory") stage, instead of the "T" stage, and
- G (for "gate") stage, instead of the "S" stage.

Le Corre's article describes with crystal clarity the speech memories that must make up a "T" stage, the first to receive a PCM word from an incoming multiplex and transmit it to a an outgoing multiplex (or to a second memory serving such a multiplex), after an interval determined by the stage's control memory.

5. Integration of transmission and switching

Prior to ESSEX, digital time-division multiplexing and switching were only isolated concepts as possible directions for the future. ESSEX brought them together. From the 1960s, the watch word became "integration". (It was as if transmission and switching were not integrated in past telecommunication networks!.. [8]; now, however, it was the integration no more of two different types of analog plant but of two digital techniques: digital transmission and digital switching.)

With the anticipated advent of low-cost integrated digital circuits, the challenge posed by ESSEX was to make a transition to an integrated digital network to take advantage of the superior characteristics of digital transmission.

Of great concern to the network planners was the question of synchronization. With time-division multiplex (TDM) lines entering a switch from many offices, the primary concern was maintaining synchronization of the signals generated by the different clocks. During the next 15 to 20 years this was a favorite topic for learned

[7] or perhaps more expressive ones (see the Remark at the end of Box A).

[8] If one wishes to play on words, it can be said that, actually, the telephone plant has always evolved as an integrated network even when it was of a completely analog nature. As transmission systems spanned greater distances, electromechanical switching system designs had to include features to make networks with these transmission improvements feasible. To obtain integration of analog facilities where the directions of the transmission were separated, four-wire switching was introduced. Other features were to accommodate different forms of dc and ac-tone signaling. Transmission loss through pads and gain through repeaters (amplifiers) were switched into and out of connections by central office switches based upon the source and sink of connections.

papers. For the most part if turned out to be a non-problem [21].

6. Military integrated digital communication

As we have seen in section 3.4, the military communities were the first to realize the potential advantages of integrated digital networks to be used for tactical deployment. Like many proponents of all-electronic switching they had been actively pursuing time-division switching in the late 1950s and early 1960s. The United States Department of Defense contracted for several PAM TMD switching systems [21,22].

Combining the robustness of digital transmission with all electronic switching offered the advantage of equipment requiring little if any field adjustments. This was of particular importance to military equipment operating by less trained operators.

Among the first proposals of all digital systems, with the French RITA already mentioned (section 3.4), there was the TIDES system presented at the Paris 1966 ISS [23], and later the British PTARMIGAN. In the United States, the Bell Laboratories in conjunction with RCA and ITT as sub-contractors developed a combined space and digital time-division systems known as UNICOM based largely on No. 1 ESS technology [24].

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CHAPTER VIII-3

RESEARCH AND FIELD TRIALS OF DIGITAL SWITCHING SYSTEMS IN THE 1960s–1970s

1. General trends

In the 1970s, almost all the countries interested in electronic switching for public exchanges hedged their bets, looking closely at both analog space-division and digital time-division switching systems.

In those days, digital switching systems were regarded as requiring long-term research of a rather fundamental nature and unlikely to produce any short-term spin-off. Consequently, they were usually the preserve of research centers directly controlled by operating administrations, as in the case of Australia, France and the United Kingdom. With a few exceptions such as LM Ericsson, Bell Northern, some of ITT's European companies and some Japanese companies, virtually all switching manufacturers concentrated solely on developing space-division switching systems.

Unlike research on space-division systems, most time-division systems were taken from the laboratory into the field for trial. This could be expected since testing not only involved the switching system but problems associated with the synchronizing and interfacing with digital transmission lines.

Most of the digital switching developments during this period, especially that by manufacturing companies, was directed to the design of transit or tandem exchanges: it was the logical start since they were the ones to be served by PCM multiplex links.

2. Italy

In the late 1950s the Italian company Telettra became interested in digital transmission as a follow-on of their successful line of analog transmission products. They were quick to recognize the significance of the IDN (Integrated Digital Network) concept. As a result they installed trial equipment in the Bonomelli exchange in Milan with a remote concentrator in the Opera exchange in July 1964 [1]. These subsystems operated with one another over a 1.544 Mbit/s PCM line which was also being tested. (The 1.544 Mbit/s line rate appeared in most early experiments since it was the *de facto* standard at the time.). This was probably the first field trial of an IDN experiment.

3. United Kingdom [2]

While the British Post Office proceeded with the development of the simpliest forms of space-division electronic switching systems (see Chapter V-6), researchers in their Dollis Hill research laboratories did not abandon the idea of an all-electronic systems for Britain. Early in 1965, a group of researchers led by K.J. Chapman and W.T. Duerdoth started to build an exchange that was later installed in the Empress exchange in London. This system used delay lines as the memory medium to carry out time-slot-interchange [3].

The Empress exchange, connected with T1-type digital lines to three nearby Strowger exchanges, was placed in service on 11 September 1968. It was heralded at the time as the world's first PCM tandem exchange.

While the Post Office was experimenting with their own form of digital switching, two British companies, GEC/Marconi and STC/ITT, were developing their own version of digital switches:

- The GEC/Marconi system was called MARTEX [4].
- Later, the ITT subsidiary STC proceeded with its own PCM tandem exchange that was placed in service in Moorgate on 15 June 1971 (see section 7, under 7.3.1A).

4. France (PLATON model, E1 system)

(see Chapter V-8, section 3 and Chapter VIII-4)

5. Australia [5]

In 1973–1974, the Research Laboratories of the Australian administration designed a model of an SPC PCM tandem exchange and proceeded with its trial at Windsor, a suburb of Melbourne. The exchange terminated approximately 100 junction circuits and performed all basic functions such as signal reception and analysis, interexchange-signaling, path selection, call connection and monitoring.

6. Japan developments for digital switching [6,7]

In Japan the "DEX" program of exploring electronic switching systems was started under the auspices of the NTT's Electrical Communications Laboratory, ECL. The DEX-1 and 2 were space-division experiments and the DEX-T1 (T1 for the "T1" transmission system,) was the time-division digital candidate.

6.1. Historical background

During the mid-1950s Japanese research and development efforts regarding time-division switching technology centered on PAM switching systems, as discussed in Chapter II-5, section 1. The major research trust then changed to PCM switching.

A PCM switch interchanges multiplexed time slots, each composed of 8 bits. Initially, serial PCM switching was studied: time slots were interchanged under the form of 8 bit serial PCM sequence [8]. Parallel PCM switching was next proposed in 1960 by Prof. T. Osatake and M. Akiyama of the University of Tokyo [9]. This switching technology provides for the serial PCM sequence conversion to 8 parallel bit sequences where each parallel sequence is switched simultaneously. Therefore, a switching network with a higher number of multiplexed time slots could be provided and most recently developed systems are based on this paralled PCM switching technology.

In 1963, a time-slot interchanging system [10] was proposed by Prof. H. Inose of the University of Tokyo. His proposal provided the interchange of time slots by using "phase shift switches". This technology made it possible to improve inner blocking probabilities for a time-division switching network. As explained in Chapter VIII-2, later developed time switches are based on the same mode of switching, but with use of LSI memories.

6.2. First Japanese developments of digital switching systems

Parallel to this fundamental research, between 1964 and 1967, NTT's K. Hanawa in cooperation with NEC Corporation developed an experimental digital switching system, the DEX-T1. This model had a switching network of the S-T-S type [11] and used serial transmission through the switching network [12]. It served 24-channel PCM links (1.544 Mbit/s) with a clock developed by K. Habara, a control system composed of central and peripheral controllers (developed by S. Yoshida) and a new network synchronization method, known as the "equational timing system" (J. Yamato) [13]. NEC was the contractor to ECL in the development of this switch which was operating in the ECL laboratory at the end of 1967.

In a parallel experiment, the Fujitsu company working with NTT's ECL (K. Habara) produced in 1965 the "KOH 40A" experimental system [14] as an alternative to the DEX-T1 time-division switching network using serial PCM technology. KOH 40A transmitted bits through the network in parallel. PCM codec technology using variable multiplexing functions and parallel PCM switching technology with 192 multiplexed time-slots using 1.544-Mbit/s clock were applied in this equipment.

Discrete components such as diode gates and capacitor memories were used in the design of these two systems. With such components, high production cost were encountered that inhibited development of commercial digital switching systems. Consequently, space-division switching technology was adopted in developing NTT's first commercial electronic switching system, the D10 system (see Chapter V-5).

6.3. During the 1970s, demand for data communications, where data terminals and computers were to be interconnected via digital communications links, increased. This intensified the need for a Japanese public network switching data circuits. On the other hand, the advances in the field of microelectronics were remarkable in those days. As a result, a DDX digital data switching system [15,16] was developed by M. Kato and H. Ikeda of NTT in the early 1970s with the help of the experiences of DEX-T1 and D10 SPC technologies. Data-circuit-switching field trial of test exchanges started in March of 1976, and the commercial service was opened in 1979. This was the first example of application of a digital switching system in a public network in Japan. Packet switching commercial services were opened in July, 1980.

7. ITT experimental models for digital switching

7.1. The ITT line of experimental PCM switching systems for public service

In the first years of the 1970s, Pulse Code Modulation (PCM) integrated switching-and-transmission systems were expected to have a major impact on future communications methods on both technical and economic grounds. The various European companies of the ITT Group were then quite active for developments in this direction. Between 1970 and 1980 three generations of PCM digital switching sytems for civil public exchanges were developed one after the other by these companies. They were called PCM-A, -B, and -C respectively.

Within ITT, these three generations were built as prototypes or as experimental plant placed in genuinely operational service during a few months only. The third generation, however, was the fruit of research by ITT's French company "Le Matériel Téléphonique" (LMT) and was actually marketed on a large scale after the early 1980s when it was no longer an ITT product but had become known as the MT System (see Chapter VIII-5). Following the takeover of LMT by Alcatel-CIT in 1984, the MT line, i.e. the MT20 (toll) and MT25 (local exchange) systems, has been marketed since the late-1980s by Alcatel NV under the name E10/MT.

Although ITT's PCM-A, -B and -C systems were never marketed as such, a glance back over their years of development suffices to reveal the interest of all three generations. Just as a geologist examines a field cut to determine the successive sedimentations that have occurred, so by studying these three generations can we follow step by step the rapid strides made in digital switching, a technology which in the 1970s was, after all, still in its teething stage.

7.2. Chronology of the three generations

7.2.1. The *PCM-A* generation [1] included two developments:

- a London tandem exchange field trial, jointly developed by STC in the United Kingdom and LCT ("Laboratoire Central de Télécom-

[1] The ITT Plan for civil developments of digital exchanges was revised in 1971. It was then decided to cover under the literal symbol "A" all work done prior to that year. This included the development of both the Moorgate Tandem exchange and the hybrid "IST" Terminal exchange.

munications") in France. It was installed as the Moorgate tandem trial exchange which was in service from June 1971 to October 1973 in the City area of London [17,18];
- an exploratory integrated switching and transmission ("IST)" system jointly designed by LCT (Paris) and Face (Italy), and tested in laboratory only, in 1973. This local exchange model was intended to check the feasibility of analog space-division electromechanical line-selectors using minicrossbars along with digital time-division group-selectors [19,20].

7.2.2. A *PCM-B* exchange was developed by BTM in Belgium (Antwerp) and LCT and was put in service for a limited period in December 1977 as a tandem Field Trial model in the Charleroi area in Belgium.

7.2.3. *PCM-C* was initially developed by LMT and LCT. After long and extensive field tests, and after changes in software and hardware components, the system was put into operational service by LMT in 1983 as a Toll exchange of the French Administration under the name MT 20 in Paris "Aubervilliers", and as a local exchange under the name MT25 in Paris "Philippe Auguste" the same year.

7.2.4. Table 1 gives the main features of the exchanges of the three successive generations which were installed for field trials in a real environment.

7.3. Main characteristics of the ITT PCM experimental systems and conclusions from their field trials.

7.3.1. Notes concerning PCM-A

A) United Kingdom

The Moorgate exchange was a tandem exchange acting between three local Strowger (step-by-step) exchanges. It consisted of:
- a distributed switching network containing space- and time-switching matrices, signaling units and interfaces between the PCM junctions and the exchange;
- a centralised control consisting of stored-program processors and wired logic units, the latter for path searching, path identification, line scanning and register scanning.

B) Italy

(1) The exploratory PCM "Integrated Switching and Transmission *(IST) system*" for local exchanges was an hybrid solution using space-division for line concentration, and time-division for group selection; it used "Miniswitch" crosspoints for the line selection units (LSU) and PCM switching for the group selection units (GSU).

General objectives of the IST development were:
- to demonstrate that space- and time-division techniques are compatible and that space- and time-division switching stages could be controlled by a single central control unit,

Table 1
Main features of the three model types

Location	PCM-A Moorgate (London, UK)	PCM-B Charleroi (Belgium)	PCM-C = MT Aubervilliers, "Philippe-Auguste" (Paris)
In service, in:	1971	1977	1983
Stored Program Processor	BTMX 16 bit	LCT 3200 32 bit	LMT μ 321 32 bit
Load sharing	yes	yes	yes
Path search	In the network	In memory	In memory
Network structure	SS-T-SS	T-S-T	T-SS-T
Network speed (Megabit/s)	1,5 Mb/s	2 Mb/s (T) 4 Mb/s (S)	4 Mb/s
Primary multiplex	24 channels	32 channels	32 channels
Target capacity (Erlangs)	5000 E.	10,000 E.	10,000 E.

- to investigate the capabilities of remote control techniques throughout the PCM network,
- to demonstrate the technical feasibility of a PCM local network for a maximum of 20 000 to 30 000 subscribers.

(2) Main characteristics of the IST system.

a) The system was designed to serve a dispersed local network, with RSU modules which could be located at some distance from the central control unit.

b) The switching network structure was of a folded space-time-space (STS) type, with full availability, and operated in parallel mode at a transfer rate of 2 048 kbit/s.

c) The central control was of the SPC type, with two identical central processing units (CPU) operating in a load sharing mode. Each CPU consisted of a processor with its memory blocks and peripheral units. The processor was a third generation machine of the ITT family, specially designed for telephone switching.

d) For signaling between the PCM main exchange and analog space-division exchanges, provision had been made for interworking with direct current (DC), alternating current (AC), multi-frequency code (MFC), and CEPT PCM transmission signaling systems.

e) The sizes of the exploratory system units were:

- Concentrators: 512 or 1024 subscribers, using standard Metaconta L line selection unit;
- PCM switch: space-time-space (STS) configuration; maximum size of 64×32 with parallel both-way transfer operation at 2048 kbit/s internal rate;
- Networks area size (target design): 32×1024 or 64×512 = 32,768 subscribers distributed over one main exchange and 0 to 7 satellite exchanges.

(3) Major findings.

The major results of the IST system development were:

- an original concept for local and remote switching network control had been implemented, the high digital capacity offered by PCM being extensively used for signaling and control information transfers.
- the feasibility of using interworking space- and time-division techniques for the switching stages was demonstrated.
- a rationalization of the interfaces between either PCM transmission/PCM switching or hardware/software had been extensively investigated.

7.3.2. Notes on the PCM-B Field Trial Model

(1) The PCM-B model, developed by BTM and LCT, was installed in Charleroi (Belgium) in an exchange building of the RTT (Belgian Telephone Administration). After preliminary test on December 1977, it was connected to two local Rotary exchanges through 120 trunks, half of them analog, half PCM, permitting 60 simultaneous calls, and put into service for a limited period.

The model was designed for 1024 trunks. Comprising 12 racks, it was controlled by two ITT 3200 standard processors operating in load sharing.

(2) Although the field tests of the PCM-B model were limited in time and received little publicity outside Belgium, it must be recognized that PCM-B contained many of the features finally adopted for the basic design of the MT 20 which ended up in the MT/E10 of Alcatel. The following aspects are relevant:

- path search in hardware was replaced by search in memory and subsequent continuity test;
- a TST network structure was adopted instead of the SSTSS structure of the PCM-A of the Moorgate exchange, due to the decreasing memory cost.
- the time "T" switches were designed as 2Mbit/s parallel switches (8 bits of a word switched simultaneously over 8 gates operated in parallel);
- the reliability of the space "S" switch had been increased by splitting it into independent planes where the bits propagated serially (4 independent planes in the Charleroi exchange);
- the "S" switch stage consisted of two identical non blocking "S-S" arrangements, one serving as standby to the other in case of failure.

PCM-B designers had also decided to adopt the unidirectional arrangement where two sets of equipment are used for the two directions of transmission, in order to eliminate the speed penalty of bidirectional space switches.

(3) The Charleroi exchange contained all the facilities needed to handle 4 types of signaling over analog and digital trunks. The functions of the interfaces between processors, switching network and signaling units were by hardware arrangements with markers, slow drivers and fast-driver scanners.

7.3.3. Notes on PCM-C: see, in Chapter VIII-5, the section related to the genesis of System MT.

8. Local time-division digital switching

All of the experiments and trials of this period (including the Bell Laboratories ESSEX, the French Platon and its successor, the E10 system, and the ITT IST experiment) depended upon space-division for interfacing the local lines with the PCM trunk facilities. The interface with the digital facilities started at the output of line concentrators. In effect the time-switches were all tandem switches interconnecting PCM trunks. This was the same motivation for the initial time-division digital switching developments in the United States as we shall see in Chapter VIII-7.

9. The first AT&T experimental models towards digital switching

At Bell Laboratories, in the early 1970s, one of the groups in the research department had begun

looking at the future and the prospects of using large scale integrated circuits in switching. Their first project in 1974 was the Digital Wire Center [21,22a]. This project pioneered in the use of the switching network for control access as well as for speech paths, a principle widely used in current distributed control switching systems.

A later project, circa 1979–1981, called the "Experimental Digital Switch" (XDS) [22b], introduced the concept of building "intelligence" into the switching network. This meant that the digitalized signals of a speech path, besides being switched within the network, also included in the speech path elements that changed the coded information so that conferencing, tone supply, etc. could be accomplished on a direct digital basis. Many PBXs and other systems at the time also contemplated the use of this feature.

10. Other North American developments in digital switching

(see Chapters VIII-6, VIII-7 and VIII-8)

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CHAPTER VIII-4

THE FRENCH E10 SYSTEM AND ITS EVOLUTION OVER TWENTY FIVE YEARS

1. The story of the E10 system like a long and gently flowing river

1.1. The French E10 system was the first digital switching system to see the light of day as a product and to become widely established in the vast international telecommunications market.

The story of the system is a perfect example of a digital system which, over the last two decades, has evolved and progressively adapted both to technological progress and to the changing conditions of the world switching-equipment market.

1.2. This story, with all of the events along the way, can be compared (to take the title of a film currently popular in France) to a long and gently flowing river.

At the source the river is still a tiny stream looking for its course and direction of flow, although this is firmly orientated towards the great sea of progress in the field of electronics.

Great rivers are made from tiny streams. The current and course of our river are determined by its environment, by the hills and terrain surrounding the bed different sections and stretches that a geographer could define. The story of the E10 is made up of as many successive stages, often determined by events controlled by the company's industrial and financial policies, new additions – tributaries that flow in and swell our river. The E10 system has evolved so smoothly that it would be difficult to identify all the different stages if a slight change in its product name had not been introduced to mark them.

2. The birth of the E10 system

2.1. A previous chapter (Chapter V-8), dealing with French switching developments in the 1960s, described:

- how the "Switching" team at France's PTT research center, the CNET, moved during the 1950s from the suburbs of Paris to the small town of Lannion in Brittany;
- how, from a period, going from 1960 to 1965, of design studies and production of models, there emerged prototype digital switching equipment known as PLATON;
- how, once the technical viability of the project sketched out by Platon was shown, it became necessary to bring companies involved in the technology of switching into the decision making process and that the main result of this was the creation of SLE (Société Lannionaise d'Electronique), a subsidiary of the "Compagnie Industrielle des Télécommunications" (CIT).

2.2. The period between 1965 and 1970 was one for the making of technical decisions:

- confirmation of system architecture. From the inception of the project, and destined to remain unchanging, the concept of "subscriber access units", local or remote, connected by multiplex PCM links to the digital "core" of the exchange, i.e. to a digital switching network, was adopted. The switching network was a square network with a single time-stage "T", and therefore no blocking. The operating speed of components available limited its

capacity to a maximum of 64 32-channel PCM multiplexes [1] connected, i.e. 2048 telephone circuits.
- in this architecture, distribution of control functions was on two levels. Firstly, specialization by function: multiregisters, markers, charging equipment, etc. Then, the adoption of the concept of "load sharing", a concept born in France and very much specific to French switching equipment.
- last but by no means least was the choice of which components would be used in the exchange, a difficult stage as it meant submitting the system to the test of its economic viability. Integrated circuits had only just come onto the market, but at what price!.. The main types of memory available at the time were magnetic (magnetic cores or cards). For certain memories, magnetostriction delay lines were retained and, for the stored programs, diode matrixes.

2.3. On 15 December 1969, a first exchange was commissioned at Perros-Guirec in Brittany, near to Lannion. Three months later it was opened for public service to 700 subscribers distributed over two subscriber connection racks. In 1970 a second exchange was installed at Lannion. It connected 2000 subscribers and also served as tandem local exchange for two other local exchanges, one of which was the Perros-Guirec digital exchange. Reliability of the system was judged acceptable as soon as the Lannion exchange came into service. Right from the start, this exchange was run "without a safety net", that is to say without the possibility of reversion to a stand-by electromechanical exchange in the event of a breakdown [2].

[1] This is the period when agreement was reached in 1968 by European countries on standardizing of 32-channel PCM multiplexes. This agreement was an important factor in the crystalizing of choices relating to transmission aspects of the digital switching project.

[2] cf. the same confidence in their system design manifested at the Morris trials by the Bell Laboratories developers of the first SPC "central office" in the world (see Chapter II-4, Box B).

The absence of any major breakdown, the better quality of conversation provided and the offer (free of charge) of a few supplementary services/facilities to the Lannion subscribers made this experiment a success with users and a pole of attraction for technicians. Engineers and technicians came, firstly from Paris and then from abroad, to visit the CNET and see the new baby. A switching system had been born, Platon grew up to be the E10.

3. A first series version of the E10: the E10A [1,2]

3.1. A major step still remained to be taken: marketing of the product, that meant production at a cost lower than the selling price to the French administration and, of course, finding new customers. Marketing was entrusted to CIT. Various modifications were made to the system, mainly concerning the choice of electronic components. The "subscriber access equipment" - space-time concentrators – now used reed relays. The long awaited arrival of MOS integrated circuits meant that magnetostriction delay lines could be replaced by shift registers, a great improvement for exchange maintenance. A new minicomputer as a control processor considerably enriched programming possibilities.

Two new exchanges were brought into service in 1972, once again in the Lannion area. This marked the beginning of the production phase known, after the version, as the E10A period. It was to last for ten years.

3.2. A factory dedicated to the production of the E10A was set up by CIT near Lannion. By 1975 its production capacity had reached 200,000 lines per year. In that same year a little over 100,000 lines were cut over to public service via clusters of local exchanges throughout the French provinces.

Orders from the French administration increased at the same time as the first steps towards exporting the system were taken (1976–1981). As early as 1973 a license agreement had been reached with Poland for the installation of a fac-

tory at Poznan and for technical assistance. In 1974 the first E10A export version exchange came into service in Poznan. Other foreign orders followed, although initially they were small (Mauritius, the Fez exchange in Morocco, both brought into service in 1976, and, in the following years, orders from various countries, mostly in the Middle East).

Along with factors relating to the rapid progress in the field of electronic components, the constraints imposed by exporting together with the requirements of potential E10A users caused a progressive evolution of the system. This resulted in the introduction of a new processor with corresponding increase in the number of programmed instructions.

In all, around 3 million E10A lines were installed in France and abroad during the ten year period which preceded the introduction, in 1981, of a new version of the E10, called the E10B.

In the E10A family, several special types of installations had come into being, in particular two 4-wire transit exchanges:

- one for private corporate networks, known as "Citedis", with a capacity of a few thousand telephone extensions;
- the other for high-capacity urban and interurban transit exchanges, for public networks [3]. This type of transit exchange had a multimodular structure including identical incoming and outgoing modules, each with a capacity of 1500 Erlangs.

4. From 1981 onwards, a new version of the E10: the E10B [3]

4.1. In the late-1970s, the CIT had become entirely responsible for the E10 system, for its technical aspects as well as the production and marketing (which had been its only responsibilities for the past period).

Although the E10A had cut out a substantial segment for itself in the rapidly expanding French market and had definitely penetrated the export market, it would have to increase system capacity and reduce cost per line if it were to make a real impact on the world market. A new version was therefore justified, not only for export but, first and foremost, for France. The implementation of the operating and maintenance standards promulgated by the administration imposed a number of severe constraints on French manufacturers. The new standards had to be respected at the same time that prices had to be reduced in view of the large expansion of the size of the market offered by the administration.

The cost per line was improved by replacing the reed relays in the subscriber access equipment with MOS circuits. This meant it was possible to have 16 line circuits per board instead of 8 and to have 1000 subscribers per rack, connected to the switching network by four PCM links (instead of 500 subscribers, by two PCM links) [4,5]. The design of subscriber access units was also modified. Connection of PCM links, initially different for remote units and collocated units, was now via a single model.

The capacity of the switching network was increased by the adoption of a T-S-T structure. Maximum access capacity for this network was brought to 256 PCM links (3000 Erlangs), then to 512 PCM links.

The structure of control subsystems was entirely redesigned around a modular concept with standardization of modules. The capacity of memories was again increased, the multiregisters having a program of 32,000 instructions (of 48 bits) instead of 4,000 in the E10A. The number of instructions was then progressively increased to 64,000 and then to 128,000 [6]. The translator memory went from 1.3 to 12 Mbits.

All of these developments could have been incorporated one by one into the E10 as improvements and would have gone virtually unnoticed. However, the fact that they all appeared at the same time justified the attribution of a new code. This was the E10B. The first E10B exchanges came into service at the end of 1980 in two middle eastern countries, North Yemen and

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[3] One of these exchanges was an underground one, installed in the heart of the business area of Paris, under the noble "Tuileries" garden, nearby the Louvre.

Qatar. The first in France was in Brest in July 1981.

4.2. Pushed by the high volume of French administration orders (more than one million lines per year) and with a competitive product suited to export requirements, the E10 system had considerable success in the 1980–1985 period. A large number of E10B exchanges were installed abroad, in Lebanon, India, Sri-Lanka, Ireland, Central America, China, etc. In India, and later China, this was in the form of technology transfers. In India, production plants were built, capable of producing several hundred thousand lines per year, with a first large factory at Mankapur (Uttar Pradesh, north-east of New Delhi) [4].

This E10 success was based on a policy of continuous and progressive product development but retention of the same basic architecture. The incentives for development were, as they will no doubt continue to be in the foreseeable future, the fast development of electronic components coupled with increasingly demanding requirements for services and facilities requested both by users and operating personnel. The ever increasing part played by software favors manufacturers who know how to control the evolution of their products.

4.3. In spite of (or perhaps because of) severe competition in France between CIT and Thomson-CSF [5], championing its MT20/25, the CIT company went, in less than ten years, from being a simple production facility for Platon according to the CNET's plans [6], to the status of a major switching manufacturer, able to impose its designs and win markets in the face of competition.

The E10B evolution did not stop at the mid-1980s [8,9].

In 1983, a major industrial event occurred in France: the merger/takeover of Thomson-CSF Téléphone by CIT. This was to form the start of a new and important step in the life of the system as this merger was to bring together two product lines, the CIT's E10B and Thomson's MT20/25, into one, called from 1986 onwards the "Alcatel E10".

5. The "Alcatel E10"

5.1. After the takeover of Thomson by CIT, a further two years, from 1983 to 1985, (and, apparently, also some executives...) had to go by before the product policy to be covered by the name "Alcatel E10" was firmly established.

The use of a single name was justified by the incorporation of a new "subscriber access unit", called the CSN ("Centre Satellite Numérique"). This unit was able to be connected to the central core of the switching system (the "coeur de chaîne" in French terminology), of either the E10B or MT25 type.

In addition to the advantages of having a single model for a unit with different applications, two other technical reasons were behind the development of this new unit:

– instead of making the analog/digital conversion after a space-division concentrator of the subscriber traffic, as it has been the case for the past versions of the E10, would not it be better to connect analog subscribers with a codec per line (a practice that had been

[4] Later, another large factory for Indian E10 production was opened at Bengalore, India's most important centre for telecommunications development and manufacturing.

[5] Thomson-CSF Telephone, created in 1976 from the partial dismantling of the ITT group in the "Frenchification" period of French industry, received, amongst other acquisitions, the LMT company ("Le Matériel Téléphonique") and LMT's project which was to be the MT20/25 system (see Chapter VIII-5).

[6] A quotation from John Meurling, in "A Switch in Time" [7] is typical: "In the 1970s, the bulk of the lines installed in France were crossbars (...). But one company, CIT, virtually unknown outside France, was beginning to attract attention at conferences and in its publications. Its system was called E10, and its SPC system was perfectly straightforward. What was new with E10 was not the control system, but the switch. The E10 switch was digital."

widespread in various countries and especially by Japanese manufacturers), in considering the substantial lowering of price for a single-line codec?
- was it not desirable to already plan for the future connection of ISDN lines?

5.2. The solution adopted for the new subscriber access unit [10] was a positive reply to these two questions and the unit was a completely digital one, with adoption of digital concentration. This was planned to provide two concentration stages:
- the first stage consisted of digital concentrators able to operate on 256 analog lines or 128 ISDN terminations at 144 kbit/s. These digital concentrators, of mixed type, can accept any proportion of analog and digital (ISDN) subscribers, with a proportion variable in time. Evolution towards ISDN can therefore be progressive by inventory control of subscriber boards, and will be able to follow ISDN demand both in terms of area covered and time.
- the second concentration stage was designed to be able to concentrate the traffic of 5,000 subscriber lines onto the channels of 16 PCM links. Control of the unit is provided by a pair of 16-bit microprocessors.

The two concentration stages can both be sited remote from the exchange and from the preceding stage. The local network structure can thus be optimized in high, average or low traffic density areas. In the event of a breakdown of the PCM links to the host exchange, the independence of the remote unit, as is common practice for digital systems of this second generation, allows for "stand-alone" operation.

5.3. The first subscriber digital access units came into service in 1986 in China in the Beijing network and were then introduced into France. It was these units which allowed for the first ISDN connections in France to be made in Brittany in the autumn of 1987.

5.4. In parallel with the modifications made to the access units and their bringing together as one common "subscriber digital access unit", the control subsystems for the E10 versions, whether used with the E10B or the MT25, i.e. for what was now the "Alcatel E10", were replaced by more powerful processors. Incorporation of such a processor unit was made necessary since:
- the capacity of the switching network had been doubled (from 256 PCMs, i.e. 3000 Erlangs, to 512 PCMs, i.e. 6000 Erlangs);
- the memory capacity had to be increased to meet the needs of new software versions (for the subscriber digital access unit, the No.7 signaling system, the Centrex service, etc., and finally ISDN).

With the addition of microprocessors, this new processor unit was designed to associate its very large processing power with a doubled multi-branch switching network able to handle a final capacity of 25,000 Erlangs (2048 PCM multiplexes).

5.5. The "Operation and Maintenance Center" (or "information processing center", in the E10 terminology) is equipped with a new Alcatel 8300 processor whose software is bottom-up compatible with previous operating and maintenance software. The performance level of this new processor, initially developed for packet-switching applications, can be used for numerous other telecommunications applications and especially to provide the processor in the new CPU for the control subsystems.

5.6. The E10 software releases have not of course ceased to be enhanced by new features since the inception of the system and their modes of development and updating have also undergone significant and steady progress.

The merger/absorption of Thomson-CSF Téléphone by CIT Alcatel led, at the beginnings of the 1980s, to the unification of most of the software of the MT25 and E10B. It was a delicate and very difficult operation. The existence of common software requirements imposed on the two companies by the French administration well before the merger was an element which contributed strongly in facilitating the operation.

6. The existence of another E10 labelled system: the E10S and E10 Five [11,12]

6.1. Alongside the above described versions of the E10 system, there was also a specific type of small- and medium-capacity exchange, which was also trade-marked under the E10 acronym: the E10S (letter "S"), also labelled E10-5 (E10 Five) in the United States.

The E10S was developed in the early 1980s by CIT-Alcatel and, for its American version E10-5 (Five), jointly with its TSS-Alcatel subsidiary in the United States. It is an SPC system characterized by a hardware and software architecture of the state-of-the-art prevalent at this period. This architecture, both distributed and microprocessor-based, is substantially different from those of the other – previous or later – versions of the E10 system.

E10S is highly modular in all its elements:

- the central control function is distributed over a variable number of microprocessor-based units;
- the switching network is made up of 2 to 4 independent parallel sub-networks, each with a capacity extendible from 32 × 32 to 128 × 128 32-channel PCM multiplexes;
- the software is partitioned into independent modules, flexibly allocated to the microprocessor physical machine.

Interprocessor communication is provided by a high-speed (1 Mbit/s) serial data link interconnecting all central control processors as well as the microprocessors of the switching network. Each processor is linked on a point-to-point basis to a controller of this interprocessor communication sub-system, which allocates the data link to the processors for message transmission, on a demand basis.

6.2. E10S was designed to be a multipurpose system. Three applications by the French administration were [13]:

- a "Multiservice" system designed to provide switching centers meeting the needs of business customers for multiservice (voice and data) between the different locations of a company or between different companies. The E10 Multiservice was used by the French administration to provide the exchanges of the terrestrial part of its Telecom 1 satellite communication network;
- a "E10 Videotex" version to implement gateways in the largely spread Videotex network (more than 4 million "Minitel" terminals in 1988) of the French administration: the E10S is the interface point between the public switched telephone network and the packet-switched data network acceeding the data-serving offices (in 1988, more than 2000 such "servers" in France).
- trial exchanges for a cellular mobile radiotelephone system.

A fourth application of the E10S was a version called E10-5 (Five) designed for the North American Class 5 Central Office market of the "independent" companies of the United States [14]. Chapter VIII-7 hereafter, covering the various local digital systems which were the first to appear in the United States, under section 9.3 mentions this system and what was its not negligible but however limited success in North America, with not more than 150.000 lines put into service, after the first commissioning of a central office of this type in 1983.

All these applications of the E10S – a family of applications – were built on a common base of software and hardware, which, for example, represented approximately 50% of the hardware and software of the E10 Five.

7. Deployment of system E10 and its following versions (E10B, Alcatel E10)

In 1976, at the time of the Kyoto ISS, more than 100,000 subscriber lines of E10 system were in service in 68 exchanges in France and, at the end of 1977, the total number of E10 lines in service exceeded 800,000 [1].

As we have seen under 3.2, around 3 million E10A lines were installed in France and abroad during the ten years period which preceded the introduction, in 1981, of a new version of the E10, called the E10B.

At the end of 1988, the "World References" booklet of CIT-Alcatel of January 1989 indicates that this company had, in service and on order, 27.2 million subscriber lines, 2.1 million transit circuits, in 1781 digital switching exchanges. These statistics cover both the initial versions (E10, E10A, E10B) of the E10 system and the last one (Alcatel E10), and also the exchanges of the initial MT system and those of the specific E10S version.

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CHAPTER VIII-5

THE FRENCH MT SYSTEM

1. A hectic history

1.1. The MT system had an eventful history throughout the 1970s and 1980s and, indeed, its existence has always been marked by its successive affiliation to different industrial groups. When all is said and done, all the changes of course in its development and deployment may be viewed as a fairly accurate reflection of the fluctuations in the French Government's telecommunications policy over the years in question.

And when we say hectic, the reader may judge for himself...

1.2. The system was actually designed within the multinational ITT group in the early 1970s. The Group regarded it as the outcome of research which was designed to launch a high-performance digital switching system onto the market, i.e. the one referred to in section 7.2 of Chapter VIII-3 as the ITT PCM model C prototype.

The prime aim behind the original research [1] was to develop *a digital transit centre*. Digital transmission was becoming increasingly widespread and there was a highly promising market for an exchange which could avoid circuit groups made up of PCM links undergoing digital/analog conversion on arriving at, and departing from, a transit exchange.

The corresponding research was carried out in France:

- in the laboratories of "Le Matériel Téléphonique" (LMT) at Boulogne (in the inner suburbs of Paris). LMT had started work on time-division (digital) switching for large transit exchange in 1971. A prototype switching network based on a 32-channel PCM multiplex structure was tested in 1973. Towards 1976, a second prototype of switching network, with a traffic capacity of about 800 Erlangs, was tested as part of a fully-fledged public telephone exchange, using microprocessors at the marker level.
- and, in parallel at the European level, in the research station which the ITT Group also had at Vélizy in the then green suburbs of Paris. The name of Professor Adelaar, an authority in digital switching at the time, deserves a mention in this connection.

1.3. In 1976 the ITT system, whose industrial future was still highly uncertain, was as it were *cradle-snatched by the French Thomson Group*, a new arrival on the industrial telephone scene. (Shortly thereafter, LMT was to become "Thomson-CSF-Téléphone.)

Indeed, that was the year when, on the eve of massive investment to make good France's telephone deficit in only six years, the French Government took far-reaching decisions. Those French switching manufacturers which were subsidiaries of foreign multinationals were virtually forced into a process of "frenchification" [2].

[1] Concurrently with slightly later efforts at ITT's BTM (Antwerp, Belgium) and SEL (Stuttgart, FRG) companies.

[2] See Chapter V, Box A.

Among other companies, the LMT company was merged into Thomson-CSF. Once the financial decisions on its purchase had been taken – and almost to its own surprise – Thomson-CSF discovered this high-performance digital switching system in LMT's research laboratories. In order to breath life into it at the industrial level, it christened it the "MT system" (initials recalling the key letters of the acronym LMT, the MT20 being a transit centre, and the MT25 a local/tandem exchange).

The MT20 system was accepted by the PTT Administration as a prototype of transit exchanges, ordered in October 1977. The system took its first and somewhat hesitant step in 1979. At the Paris ISS in June 1979 (the one at which a world consensus in favour of digital switching was reached), Thomson-CSF-Téléphone was able to present an initial sample of the system, installed as an MT20 (3000 Erlangs) transit centre at Aubervilliers (in the northern Paris suburbs) and finally placed into service in 1981.

1.4. Owing to a few early teething troubles requiring a number of software modifications, replacement of the initial integrated circuits by higher performing components, the system was not actually deployed until about 1982–1983. However, with important production-cost reductions due to these improvements, it finally made a large entry into the French network.

In the full euphoria of massive investment in its telephone network, the French administration started ordering many MT exchanges:

- For its long-distance network, in full digitization of its circuits, the French administration selected the MT20 system to equip national transit exchanges: about thirty of these exchanges, including international transit centres, were ordered, most of them being put into service in 1984.
- The first MT25 exchanges (local exchanges) were commissioned as trial exchanges in Paris (Berny exchange in 1982, and Philippe-Auguste exchange in 1983). Between November 1983 and December 1984, in a crash program of modernization and expansion of the French network, more than 100 MT25 exchanges, serving about 1.8 million subscriber lines, were put into service in the French network.

Major export orders also ensued. Marketing of the MT system abroad benefited from two factors:

- the quasi-absence on the market of competitive models capable of providing a national network [3)] with a large-capacity transit centre, at a time when the circuit groups were becoming increasingly digitized;
- the drive of professionals inured to all the subtleties and harshness of export markets which were now pursued by the new parent company Thomson-CSF, an electronic firm known throughout the world in an armaments context (missiles, surveillance radars, etc.). The large contracts signed for such equipment with countries in crisis or open war (e.g., Iraq) were not unsurprisingly accompanied by equally important orders for MT exchanges.

The MT production by Thomson-CSF-Téléphone gradually supplanted its manufacture of both its Metaconta system and the AXE system also manufactured by this company under the 1976 licence agreement concluded with LM Ericsson when Thomson had taken over not only LMT but also Société (Française) des Téléphones Ericsson (STE).

1.5. There were further problems over the MT system's industrial affiliation in 1983 and 1985:

- Following a political change in France, the new Socialist Government *nationalized* the Thomson Group in 1982 [4)];
- In 1983 a further concentration of France's switching industry occurred with the blessing of the French Government (at this time, 100% owner of the two companies concerned). *Thom-*

[3)] a national network with digital routes using PCM links of the "European" standard (32-channel PCMs).

[4)] As well as the CGE-CIT Alcatel Group, although this one managed to regain its freedom as a private enterprise in 1987 during the brief return of a non-Socialist parliamentary majority between 1986 and 1988.

son's activities in the switching sector were *taken over by CIT-Alcatel*, which had itself been nationalized in 1983, and the MT system became one of the two which CIT-Alcatel was about to start producing and marketing.

1.6. Our account of the E10 system (Chapter VIII-4, in section 5) describes how the E10 and MT systems then *merged* to form two parallel versions of the same system, namely the one known thereafter under the generic name "Alcatel E10" [5]. Their merging was manifested essentially in the form of:
- a difficult and incomplete unification of software,
- the standardization for local exchanges of a single "digital subscriber connection unit".

1.7. To Frenchmen and foreigners alike, the successive stages in the MT system's life must appear extremely complicated. Perhaps only in Italy are so many about-turns and changes in the industrial scene to be found. Sociologists will no doubt claim that this was simply a reflection of a Latin temperament, bent more on rigging short-lived industrial schemes than on maintaining continuity of direction in the business world.

This brief background of the MT system history may provide the reader with a further key as to one of the underlying conclusions of this book, namely that:

"The success of a switching system is determined less by the technical merits of the engineers who design and develop it, than by the industrial and financial power of the groups which produce and market it."

2. Characteristics of the MT system [1]

2.1. Given the relatively short time the MT system lived, at least under its own name, the description of its characteristics could have been brief. If, however, it appears here somewhat detailed, it is because those characteristics reflect the long years of research carried out within the ITT Group to develop a digital time-division switching system. Moreover, the technical descriptions given of the MT system [6] offer a highly representative model so far as the digital switching systems of the early and mid-1980s are concerned, i.e.:

i) the way they were developed,
ii) their general architectural principles,
iii) the use in their hardware of new elements emerging from the latest developments in the electronic technology.

i) and ii): As in the case of nearly all first generation time-division digital systems, the prime target in developing the MT system concerned the "core" of the system, i.e. digital switching of PCM multiplexes, to provide a digital transit centre serving circuits using PCM links.

A second phase of development related to the production of local exchanges serving subscriber lines. Subscriber connection units used space-division switching to concentrate the traffic of a group of subscribers, then effect an analog/ digital conversion for passing their traffic on to PCM multiplex links. Grafted onto the above "core" structure (switching network and central control), the subscriber connection units provided (as in the E10 system) a local exchange structure.

iii): The other characteristics typical of the various digital systems which emerged in the early 1980s are the use of new electronic elements both in the system's architecture and its hardware design. Such elements were the result of the then considerable advances in integrated circuit technology. In the MT system they were

[5] During some years the original MT system was called by the CIT-Alcatel group the "E10-MT", before the label "MT" disappeared when the generic name "Alcatel-E10" was adopted.

[6] More specifically, the descriptions of the MT20 (transit centre) and MT25 (local exchange). As we shall see in section 5 below, besides the MT20 and MT25, the MT family included an MT35 version as a small or very small capacity exchange. Its architecture differs radically from that of its older brothers and represents the fruit of research conducted by Ericsson's French company STE which was taken over in 1976 by Thomson at the same time as LMT.

used in a way that was highly novel at the time. We refer to:

- the use of off-the-shelf LSI integrated circuits [2]. These were incorporated chiefly in the modules forming the particularly compact MT switching network, as well as in the successive versions (MU320, MU321) of the system's central processor [7];
- the generalized use of microprocessors [3,4], foreshadowing the general trend from the mid-1980s onwards to the "decentralized control" principle. Section 3 below refers to the various commands given by microprocessors in a MT architecture.

3. Functional characteristics of the MT20 transit exchanges [1,5]

3.1. The MT20, developed for intracity, intercity and international transit exchanges [8], comprised essentially a switching unit, a control unit and a signaling unit.

3.2. Switching unit

The switching unit consists of the switching network, controlled by dedicated microprocessors; of microprocessor-based peripherals for passive continuity checking of switched paths; of digital tone and recorded announcement distributors and of the exchange clock.

The switching network (initial version) can connect up to 64 groups of 32 PCM multiplexes. Its total capacity of 2,048 PCM links corresponded to a maximum traffic of around 20,000 Erlangs. Under normal conditions, about 400,000 BHCAs could be handled by the main control (MU320 processor), a value increased to about 800,000 BHCAs with the use of a second-generation processor (MU321).

The T(S″)T switching network is made up of time-switching modules, space-switching modules and transmission interface modules. For exchanges with a capacity between 400 and 5000 Erlangs there is normally no space-switching module, whereas two such modules are needed at exchanges with a capacity above 5000 Erlangs.

The switching network is divided into two independent branches between the input switching interfaces and the ouput switching interfaces, calls being shared on a random basis between these two branches by a branch selector. Under normal operating conditions with both branches in service and without the use of space-switching modules, the blocking probability is less than 10^{-5} for an average traffic of 0.75 E per time- channel. When space-switching is used, the blocking probability under the same conditions is less than 10^{-20}.

a) Each time-switching module connects 32 PCM multiplex links (1024 channels). Received 8-bit samples from the 32 multiplex links are serial-parallel converted and then switched into the input time-switch. After demultiplexing and parallel-serial conversion, each sample is forwarded over one of 16 serial links to an output time-switch through a space-switching module when provided. Each time-switch operates at a rate of 8 Mbits/s. Transmission on the serial links between input and output time-switches is at 4 Mbit/s.

b) The space-switching modules, when provided, route samples between the input and output time-switches of the time-switching modules. Each space-switching module is comprised of 2 cascaded space-multiplex-switches: $(8\times16+16\times8)$ outlets.

c) Transmission interface modules. Each transmission interface module serves 8 external PCM links and includes code converters for transforming the HDB3 line code to the system's internal binary code and vice-versa.

The connection units for non-digital trunks providing the analog/digital conversion are external to the exchange.

d) Switching network control. The various elements (time-switches, space-switches and branch selectors) of the switching network are controlled through programmed marking peripherals.

3.3. Control unit

The *architecture* of the MT20 has a three-level structure:

- a main control, comprising two MU320 (or, in a new version, MU321) processors operating in the call load-sharing mode;
- microprocessor-based control peripherals, handling many of the repetitive tasks;
- telephone peripheral equipment.

3.4. Signaling unit

The signaling unit comprises a set of devices for receiving and transmitting signals to/from distant exchanges. The devices are connected to the corresponding interexchange trunks through the switching network. Each signaling module is connected to the switching network by a standard

[7] The MU320 central processor was the Thomson-CSF-Téléphone version of the ITT 3202 load sharing processor. The MT system was actually the only "fully SPC" time-division system developed in France before the E10-S system.

[8] International transit exchanges of the MT system were ordered by the French PTT and a number of foreign countries, including Greece (Athens ITC placed into operation in 1981), Bulgaria, Columbia, Irak, Jordan, etc..[10]. The international system included an operator service sub-system [11].

32-channel PCM multiplex and can therefore simultaneously service 31 signaling channels.

The main varieties of signaling modules are channel-associated signaling modules, MFC signaling modules and common channel signaling modules. The signaling modules are each built around a microprocessor and perform a range of preprocessing operations to free the main processors of simple, repetitive tasks.

3.5. Software of the MT20

The MT20 software has a modular structure, organized as functional subsystems:

- each subsystem operating on its own data, with no data common to several subsystems,
- each subsystem ignoring the internal structure of other subsystems, which it sees as "black boxes",
- subsystems communicating with one another by means of messages.

The MT20 software language is a high-level language, the LP2 (PAPE), used for about 80% of the main processor software. The remainder, for greater run-time efficiency and easier interfacing, was written in assembly language.

4. Functional characteristics of the MT 25 local / tandem exchanges [6]

The MT25 is a digital system for local/tandem exchanges of large capacity. It derives directly from the MT20 by addition of "subscriber connection units" (SCUs) connected to the MT20 switching unit. This enables the possibility of forming local exchanges and combined local/tandem exchanges. The SCUs, each of 1000 lines (initial version), are microprocessor controlled. Each of them is linked to the "core" of the exchange via 4 PCM links and they can be hooked locally or as remote units. The remote units for the system were known as "URNs" while the ones associated with the exchange were designated as "UTNs".

5. Alongside the MT20 and MT25, a small rural MT type: the MT35 [7,8,9]

At the bottom of the MT system family, there was also a specific type of small exchange, the MT35. The MT35 was designed to equip small and medium size exchanges, from 500 to about 15,000 subscribers, for serving small telephone communities of the sort so common in developing countries. French-speaking Africa, which was a captive market for French manufacturers, and Latin American countries were the primary targets for MT35 marketing.

The MT35 was an SPC digital system with an architecture based on two concepts: compactness and linear growth of equipment with capacity. The basic module is a single rack, itself a fully-fledged exchange for up to 1000 subscribers and capable of handling 7000 BHCAs. Higher exchange capacities are obtained by associating a number of such racks, interconnected locally or remotely by PCM multiplexes.

The MT35, appeared in 1982–1983, was chosen to equip a number of small exchanges in the national Chilean network.

6. Deployment of the MT system

6.1. In 1984 a large number of MT20s (about 30) were in service in the largely digitized French network to equip nearly all its traffic nodes, as urban transit centres, long-distance transit centres and international gateways [10,11].

There were also large export orders for the MT20, generally for international gateway centres. At the time of writing (1989), they serve international traffic in about 20 countries, the majority of them in Africa and the Middle East.

6.2. In 1989 there are about 3 million lines of MT25 local exchanges in the French network. About 600,000 MT25 lines were sold for export, mainly to Iraq, Lebanon and Chile [9].

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[9] The absorption of Thomson-Csf-Téléphone by CIT-Alcatel in 1985 and the subsequent marketing of what had initially been MT type under the single name of "Alcatel E10", particularly in the issues of the Alcatel-CIT "World references" statistics of switching equipment produced by this company, makes it difficult if not impossible to determine whether the figures relate to equipment initially of MT or E10 architecture. (Indeed, that is precisely as the Alcatel Group intends!)

At the Florence ISS 1984, P. Lucas, reviewing the MT system in [12], gave a figure of 300 MT exchanges in service or on order in 17 countries, totaling a combined capacity of 6 million "equivalent lines".

6.3. *Licensing contracts*

As early as 1979 an important contract covering license rights, technology transfers and the supply of engineering services, production facilities and technical and industrial assistance was signed with the USSR for the construction there of a large plant manufacturing MT-based digital exchanges, with an annual production capacity of one million 0.17-Erlang lines. This contract was the outcome of many years of negotiation between LMT (from the time when it was an ITT subsidiary) and the USSR for the supply of a factory for producing electronic exchanges.

This contract, which included the delivery of two MT exchanges (one in Leningrad), gave rise in the 1980s to large-scale production of Russian MT-derived equipment at a brand new switching factory in Oufa.

The type of MT system which was developed in the USSR may be qualified as a "clone" of the original MT system, due to many different characteristics, especially in the local/tandem exchange model:

i) a special version of the "subscriber connection unit" provides for a higher traffic per subscriber line (it is therefore connected to the core of the exchange not by 4 PCM multiplexes, but by 6 or 8 PCMs) and utilizes components of specific Russian types;
ii) a different version of the central processor is used, the French MU320 having been refused for a technology transfer under the "COCOM" regulations restricting this type of transfer between socialist countries and the Western world;
iii) and, as a result of i) and ii), the software is substantially different.

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CHAPTER VIII-6

IN THE UNITED STATES, AT&T'S DIGITAL SWITCH ENTRY NO. 4 ESS, FIRST GENERATION TIME-DIVISION DIGITAL SWITCHING

1. Introduction

The development of the No. 4 ESS, the first SPC time-division digital switch, was a tremendous accomplishment for AT&T. It came at the right time and the right technology. It was a triumph for the designers as well as technology.

AT&T had first demonstrated time-division digital switching in the late 1950s (see Chapter II-4). From this research came not only the basic concepts in TDM switching but also a key person who had participated in that experiment, H. Earle Vaughan. H.E. Vaughan had left Bell Labs research in 1962 to head up the ongoing development of the No. 1 ESS. It was here that he learned of the power of stored program control.

In 1967, assigned to head the development of a new toll electronic switching system, he here combined his knowledge and beliefs in these two basic switching concepts to convince those responsible for the underwriting of this development that digital TDM with SPC was the best course to pursue. From this effort sprung the most powerful switching system developed to date, one that far exceeded expectations with respect to capacity and savings.

2. The growth of long distance calling in the United States

Direct distance dialing ("DDD") started in the United States in 1953. Its deployment grew rapidly and the service improved, particularly with respect to automatic billing. Not only did the DDD service grow but, largely as a result, long-distance telephone rates were reduced, thus stimulating traffic. By 1960 the conversion to DDD was well along and the growth in traffic was at least 12% per year. About this time, studies initiated at AT&T indicated that, with this growth in traffic, the number of the No. 4A Toll Crossbar switching offices then being installed to serve the traffic would increase to a point where by the late 1970s large cities such as New York City and Los Angeles might require as many as 10 to 20 of these toll offices.

When more than one toll switch is required for a city, the trunk field must be divided with associated inefficiencies. Studies indicated there were great economic advantages if these trunking inefficiencies could be reduced or eliminated by introducing a switch with a larger trunk and switching network along with an adequate call attempt capacity.

3. The predicted future needs

As early as 1962, plans for an electronic switching toll switch were being studied. The capacity requirements were based upon predictions of the number of No. 4A crossbar offices that were scheduled to be placed in service well into the 1980s assuming continued growth of toll calling. From these projections 370 4A crossbar toll switches would be in service by 1985. In New York City there would be 18 switches and 10 in Chicago. Most large cities would require at least 5 toll offices.

Assuming that the ESS would have a capacity of approximately three times that of the 4A crossbar offices, the expected demand number of new systems would about double. This helped to justify the large anticipated development costs and the cost of tooling for manufacture.

If the electronic system were available by 1977, the demand would be for 120 of these ESS offices. More important, the number of new offices required by 1985 would be reduced by 45 offices. New York City for example would by 1985 have only 11 offices. If further advantage were taken of the large ESS offices to replace the smaller existing 4A crossbar offices, the number of toll offices in New York City would be reduced to 7 offices [1)].

4. Planned evolution of the No. 1 ESS for toll application

Keeping in mind the earlier problems with capacity in No. 1 ESS (see Chapter V-1), much study went into assuring that the objective of three times the capacity of 4A crossbar could be attained. The design objectives were set at 70,000 trunk terminations, 350,000 busy hour call attempts (BHCAs) and a switching network capability of about 20,000 Erlangs. These were much larger than any switching system had ever attempted up to that time.

Experience had already been most favorable with the maintenance of electronic switching systems. The new development was expected to benefit not only from this experience but also to integrate trunk facility maintenance with the switch maintenance resulting in considerable craft personnel savings. These expectation gave credence to the study assumption of ESS toll systems replacing earlier 4A crossbar systems.

Despite the need for a large toll switching system, there continued to be a need for a smaller modern system. After it was decided to develop a new system for large toll applications, the development of two-wire and special Hi-Lo four-wire versions of the No. 1 ESS toll continued (see Chapter V-1) [1]. When the time-division digital No. 5 ESS became available a toll version of this system took over the market for smaller toll offices (see Chapter IX-3).

5. What type of switching network?

As early as 1966 the Systems Engineering organization assigned personnel to study the possible development of time-division digital switching to compliment the successful deployment of digital transmission. By 1967 there were over 16,000 T1 systems in operation in the Bell System.

After the first No. 1 ESS office was placed into service, H.E. Vaughan moved from research to No. 1 ESS development. In April 1968 he was placed in charge of the development of this new toll system. The system initially was known as the No. 1 ESS toll system since it was expected to be an evolution of the No. 1 ESS employing space-division technology and architecture.

Most of the engineers brought in to work on the toll project were previously on the No. 1 ESS local switching development. Their first approach was to evolve the system they knew best into a toll switch. This meant replacing the two-wire ferreed network with a four-wire network to better interface the analog carrier systems then in wide use in the U.S. toll network. The design of four-wire ferreed switches was available from an earlier military network version of No. 1 ESS (see Chapter V-1).

While the use of the four-wire switch would have required a minimum of development effort, there was a confluence of two strong factors that ultimately changed the course of the toll switch development. One was H.E. Vaughan's deep-seated interest in digital time-division switching (see Chapter II-4) from the ESSEX experiment. The second was the indicated rapid growth of the new T1 digital transmission systems for which production had begun in 1962.

[1)] Unfortunately these prediction cannot now be confirmed since the traffic growth and AT&T network requirements have changed due to the introduction of competition into the toll business and the Bell System divestiture that took place in 1984.

6. Typical Bell Laboratories Project – by committees and personalities

Task groups were established to study the possibilities of different design approaches for the switching network for the ESS toll system that would better integrate with the T1 digital lines [2]. Separate design teams were established, each to study a different approach: four-wire Hi-Lo (see Chapter V-1), semi-conductor space-division, delta-modulation time-sharing, and pulse code modulation (PCM) time-division [2]. Each of these approaches had its proponents and a study committee was established for each.

At the time, great enthusiasm for a time-division approach was only from a small, and generally less vocal, group of engineers, led by H.E. Vaughan. The capacity requirements of at least 70,000 trunks suggested a break with the past. A switching network using the added time dimension could pack a great deal more capacity into a smaller space.

Like many exploring a new approach to switching in those days, the system designers were at the mercy of the developers of the needed devices employing new technology. The success of many digital telecommunication proposals at the time looked to the new fabricating techniques of integrated circuits (see Chapter IV-4). No. 1 ESS had originally chosen not to employ semi-conductor crosspoint devices, but since that time the device developers had continued to explore the use of these devices for switching [3].

7. The "Time" was ripe for a change in direction [3]

By December 1969 all studies had been made and the PCM time-division approach was found to be slightly less costly than the competing designs. After many comparative technical and economic studies in which the PCM time-division approach seemed to show a slight projected economic advantage, its choice for development was recommended by W.H.C. Higgins, Bell Labs. Vice-president of switching. The favorable and rapid growth of T1 carrier added to the formal studies and tipped the scales toward the time-division choice.

Higgins recommended this choice to the Switching Council composed of top management people from AT & T Development and Research, Engineering, Long Lines, and Western Electric. While not all were enthusiastic on this choice, as usual they trusted the technical and engineering judgement of Bell Laboratories, provided, as discussed, the choice would not delay the development.

All present sensed that the decision was momentous and that it was time for a change of direction for switching in toll and tandem applications. The system code chosen, the No. 4 ESS, not only added emphasis, but also indicated that, for the market, this system was the replacement for the No. 4A Toll Crossbar System.

Design of the time-division network was much more sophisticated than anything attempted up to that time. Its capacity objective of 107,000 trunk terminations was greater than the original requirements. The network used the time-space-time principles.

The terminal to be used for interfacing with digital facilities, initially for T1 carrier systems, was called a "digroup", representing a set of five T1 DS0 groups of 24 channels. The code name for this set of 120 digital channels was "DS-120". The digroup included terminal functions for the T1 lines as well as the interface to the switching system.

One subtle arrangement was the introduction of decorrelation in the input time-stages with a nominal expansion of 120/128. Each of the 128

[2] With the demise of the AT&T monopoly, the making of such exhaustive studies before deciding upon a development direction for such a large project is probably no longer feasible or affordable. For No. 5 ESS the basic design direction was determined by a small group in three days (see Chapter IX-3).

[3] These device development efforts finally paid off when low level semi-conductor crosspoints were chosen for use in the 10A remote switch (see Chapter V-1) and the high level crosspoints were used in No. 5 ESS (see Chapter IX-3). The Hi-Lo network was used in the small toll/tandem office version of the No. 1 ESS (see chapter V-1).

time-channels was assigned 16 bits. In addition to 8 bits for the speech samples, one bit was a parity check of the transmission through the switch and the remaining 7 bits were unassigned initially but reserved for future service applications. Therefore the basic clock rate was 16.384 MHz. The new technology enabled this pulse rate to be achieved.

The large size required of the switching network was equivalent to a 1024x1024 space-time multiplex stage network. Instead of employing a single stage, this part of the switching network consisted of four space-stages, made up of eight 256 by 256 two stage arrays. With 128 time-channels this provided 135,000 network paths. This made the network nearly-non-blocking with, at first trial, a loss probability p = .005 with 90% termination occupancy. The network had a capacity of 47,000 Erlangs.

Since the switching network used active electronic components, each of which serving many calls simultaneously, it was duplicated to insure reliable service. This was the first time that redundancy had been introduced into the switching network of any switch.

8. Time-division, a natural for tandem switching

The in-band signaling and transmission (pad) equipment was packaged into a variety of "terminals", each serving 120 trunks of the same type. In addition to interfacing with the trunks and the switching network of the No. 4 ESS, terminals also are the inputs to the control portion of the system. Terminals included the service circuits, such as multi-frequency receivers.

As for most intermediate office applications, the system could function as a tandem or transit office to interconnect trunk terminals of a variety of different types, from electromechanical and electronic local offices as well as a variety of intertoll trunk facilities.

With the rapid growth of digital facilities in the network of local offices, the initial market for this type of switching system was clear. It was to be used as a gateway to the toll network and for application in cities where large tandem offices could be used effectively [4].

9. One processor for two projects [4]

There was a confluence of a number of events and requirements that had a great influence upon the design of the control portion of the No. 4 ESS. The most important of these was the rapid progress being made in the development of larger scale integrated circuits (see Chapter IV-4). The designers of the control portion of the No. 1 ESS were looking for faster technology to replace the highly specialized technology used in the initial ESSs.

Ferrite sheet RAM memories had already been replaced with magnetic cores. The magnetic twistor cards for the ROM storage needs were becoming cumbersome with more frequent than expected program and translation changes.

A technology using intermediate scale integrated circuits was evolving for use in a new processor for the No. 1 ESS. The technology was called "1A Technology" and the processor was called the "1A Processor". The circuit boards, later known as BELLPACS, were designed to accommodate a maximum of 52 silicon integrated circuits that initially were relatively small scale.

The 1A processor was much faster than previous designs, with a 1.4 microsecond instruction cycle compared with 5.5 microseconds for the No. 1 ESS processor. The same technology would be used for implementation of the switching network.

With so much emphasis on the switching network, it was soon decided that the 1A processor would adequately serve as the central control for the No. 4 ESS. The objective call carrying capacity at this time was 350,000 BHCAs, i.e. about the same as for the No. 1A ESS which required

[4] It should be pointed out that all initial successes with time-division digital switching around the world was where the digital trunks were deployed such as in a tandem or toll switching environment.

much more real time to process a local call as compared to a toll call.

Furthermore, it was assumed that some call processing, – pre-processing – , would be performed between the terminals and the central control of the No. 4 ESS. This was a continuation of the signal processing concept used in the larger No. 1 ESS offices. However, here, the implementation was complete with a number of signal processors in the office, each serving approximately 4,000 trunks. For example, the signal processor for digroups included interpretation of the in-slot signaling on digital trunks. The signal processor for analog trunks included taking signaling information from the service circuits.

In many respects this is the same concept as the "regional processors" of the AXE system (see Chapter V-10), except that in the No 4 ESS the signal processors are all performing the same basic functions, different though they might be for different types of trunks.

In view of the sad experiences of overestimating the attainable call attempt capacity of earlier (and perpetual?) electronic switching developments, the designers of the No. 4 ESS were cautious about predicating the actual capacity of their system. The 350,000 BHCAs figure remained until a just before the first system was cutover on January 17, 1976, when the figure was raised to 550,000 BHCAs. This was a dramatic increase and provided a real surprise to those following the project and observing the initial office cutover.

The 1A technology was more than new integrated circuit beam-leaded chips; BELLPAC circuit boards, shelves, and backplanes for interconnecting them;, and a power and signal distribution technique. It represented also a complete set of automated design tools, called "SPICED" (System of Programs for Integrated Circuit Equipment Design) and "GRAD" (Automated Equipment Design Documentation) that had been adopted for earlier applications [5].

The 1A processor was developed with two major software objectives. One was the upward compatibility for the programs written for the No. 1 ESS. The processor had to be able to emulate these programs, thereby saving a great deal of program rewriting when used as a retrofit processor for the No. 1 ESS.

For new programs, which included most of the No. 4 ESS programs, a second objective was to accommodate modular programs written in a higher level language. This language was known as "ESS Programming Language" (EPL).

Sufficient call processing programs had been written and debugged by November 2, 1972 when the first call was placed through a laboratory model of the switching network, with the use of a No. 1 ESS processor. The first call obtained with the use of a 1A processor was on May 30, 1973, exactly 8 years from the cutover of the first No. 1 ESS.

10. Nothing like success

Unlike other initial efforts in digital switching, the No. 4 ESS was not predicated on a trial or field test. As in most large projects, Bell Laboratories and AT&T proceeded with great confidence in the development and deployment of their large capacity toll system undertaking. By the end of 1976 four offices were in service. Nine more offices were placed in service by the end of 1977, and in 1979, 37 were in service. Already in 1976 an addition (extension) for digital trunks had been made to the first office.

But for those who like to declare to be the first there was one slight flaw in the initial introduction of the No. 4 ESS. It was, indeed, the first time-division digital switching system with stored program control, but unfortunately all of the trunks in the initial "Chicago 7" office were analog trunk circuits [5)]. The digroup terminals were not to appear until the second office which was cut over in Kansas City, Missouri, on July 3, 1976.

The initial installations were planned over the development period, from 1969 to 1976. At the

[5)] The honor for the first stored program control time-division digital system goes to the small toll system of Vidar (IMA or ITS4) (see Chapter VIII-11) that was cutover on March 26, 1976 in Ridgecrest, California.

time, deployment plans for the future contemplated new offices for growth of toll service and a consolidating of multiple installations of No. 4A Crossbar offices [6]. During this development period most of these offices were being outfitted with SPC processors (see Chapter V-1) and being prepared for common channel signaling (see Chapter X-6).

It was expected that about 50 of these offices would remain in service well into the 1990s [6]. But the excellent performance and expense savings of the No. 4 ESS resulted in an accelerated replacement of the No. 4A Crossbar – ETS offices. From a peak of about 180 offices of this type in the mid-1970s, by the end of the 1980s almost all had been replaced. Part of this acceleration at the end was due to the rapid deployment of digital connectivity by the introduction of optical fiber cables for long distance circuits.

But the principal item contributing to the overwhelming success of No. 4 ESS was the saving to maintenance and administrative personnel. The saving was almost 3:1. The main reason for these savings was the "maintenance and administrative centers", described in section 12 below, that were an integral part of the development.

11. Costly development

By the time the No. 4 ESS development was authorized, industry, particularly in the United States, started to recognize that the cost of developing modern electronic switching systems was becoming expensive. In the case of No. 4 ESS, it was difficult to determine the true and complete cost since many items were developed for several applications, e.g the 1A processor, BELLPAC packages, integrated circuit chips, etc. It was, however, stated [7] that the development cost US $400 million, four times the No. 1 ESS cost 11 years earlier. (Also included in the total cost were such things as factory test set designs and the programs for the development tools [5]).

[6] The fourth installation of No. 4 ESS in Dallas, Texas, replaced two 4A Crossbar offices.

12. More than a switching system – maintenance and administrative centers

Other items were included in the No. 4 ESS development. Built into No. 4 ESS were interfaces, hardware, software and data bases for operation with maintenance and administrative subsystems. Broadly these are called the Circuit Maintenance System (CMS). These were in addition to the usual Master Control Center for the switch itself.

As with all switching systems, the translation information was stored in the system. About this time such translation took on the more modern title of a "data base". Furthermore the memory available for enlarging the data bases was greatly increased as a result of the use of disk memory in the 1A processor.

The translation, including recent changes used in the switch for interpreting the called address, was expanded to include other information that is useful to the maintenance forces. The system included at least seven data bases such as the 1A processor data base. They were interfaced with five operational systems, such as the Centralized Automatic Reporting on Trunks (CAROT).

These data bases and the operational system were interfaced with personnel through three centers: the terminal equipment center, the trunk operations center and the machine administration.

As the AT&T network grew, techniques to controlling the flow of traffic were developed. Traffic data were collected in almost real-time from the various common control switching systems in the network. The No. 4 ESS also included such reporting means but, in addition, the software of the system was greatly expanded to include such things as counting ineffective call attempts to the trunk routes to which the switch could send traffic. One specific algorithm was to determine destinations that were "hard to reach" so that errors could be located in network data bases.

Generally speaking, the whole concept of network management took a large step forward with the features initially provided in the No. 4 ESS [8].

13. A dynamic design [9]

The design of the No. 4 ESS was not stopped after the initial development phase. Despite the fact that the market for such a large switch was limited (no more than about 150 switches), the switch design continued to evolve.

Within five years every frame of the switch was improved. The system as a whole was reduced in cost and space-requirements by more than 60%. A new No. 4 ESS in Chicago took only one-third of the floor space of its two predecessor No. 4 ESS offices that were sold to the local telephone company for tandem applications.

A major change was the replacement of the magnetic core stores by integrated circuit chips, resulting in an instruction cycle of 0.7 microsecond, which improved the processing capability by 30%. With the faster memory and program improvements the system was raised to a peak traffic capability of 700,000 BHCAs.

The software grew from 1.4 million stored words to 2.1 million stored words. It used an improved high level language called "EPLX" (EPL extra).

To provide further expansion in system control capability an "attached processor", a 3B20D computer, was added to the system control to relieve it of some tasks that are not as real-time sensitive as the tasks assigned to the main 1A processor [10].

Being a time-division system, several important new concepts unique to this type of switching technique were added to the system. For one thing, service circuits were designed to recognize the digital signals representing analog tones without converting them back to analog. As a result, digital multifrequency receivers were introduced. Also digital tone generation was introduced, eliminating analog oscillator circuits.

By assigning a time-channel in one stage of the switching network to a recorded announcement, all calls requiring the same announcement could be assigned to the same time-channel. A subsystem was developed to provide the recorded messages in digital form for distribution to various time-channels. This high-volume recorded announcement subsystem is called the "mass announcement system". It also provided for priority forwarding calls at a set rate to a particular destination, with all other calls receiving a recorded announcement.

Another service that was facilitated by time-division was Dial-Up Audio-Video Conferencing [11]. A Network Services Complex [12] provides not only a means for customer dialed conferences but coordination conference between several No. 4 ESSs at different locations in the United States.

With the large capacity network, a feature was provided to "nail-up" digital connections. These could be specified at the master control center for establishment and disconnect on command or at a particular time.

Because some services require end-to-end digital connections, it is possible to specify on some routes connections only over digital facilities. Originally echo suppressors and later echo cancellers could be included in connections as required, for example on satellite facilities.

With AT&T divestiture, it became advantageous to implement a new routing strategy for the AT&T network. This strategy is known as Dynamic Non-Hierarchical Routing (DNHR) [13]. With the extensive data bases of the switch accessible in real-time, it is now possible to preprogram as many as 16 (maximum 21) alternate routes for each destination. This routing may also take into account the time of day as well as traffic conditions. By using DNHR the average number of switches through which a connection passes is reduced. It has been estimated that this new networking technique will save over $500 million over ten years.

14. Exporting the No. 4 ESS

The No. 4 ESS was designed to act as a United States international gateway in 1977. This included CCITT No. 5 and 6 signaling systems. Since the digroup only operated with DS1 format, 24-channel T1 format, the system as designed could only be sold into countries where this was standard. Taiwan and South Korea are countries where this standard prevailed. The sys-

tem was sold to Taiwan in 1979 and cutover in May 1981. South Korea cut over the first of six offices in May 1983

At AT & T International, in 1983 consideration was given whether development should be undertaken to develop a 32-channel standard system. After much deliberation, the proposal was abandoned due to the relatively large development cost for the potential market size. This is typical of a type of decision that international competitors in the world switching market must make: "Is the market large enough to justify the cost of making the necessary system modifications to satisfy local requirements?"

For their Digital Derived Services Network DDSN (the so-called "service 800"), British Telecom used a Network Services Complex of No. 4 ESS modified for 2.048 kbit/s 32-channel PCM standard.

15. Still the mainstay and new applications

With the divestiture of the Bell Operating Companies from AT & T and the growth of competition in the toll business, AT & T became more dependent than ever upon the flexibility of the No. 4 ESS SPC and its access to the common channel signaling network. It became necessary to include in its design many new features and offer many new and competitive services and features.

In particular a phenomenon known as "bypass" had evolved in the United States. Customers with high volumes of toll calling required to be connected directly with the interexchange or toll companies (carriers), in bypassing local exchange companies. Some private network customers use the toll switches to form "virtual" private networks, and others preferred to use software-defined networks (see Chapter X-6) to obtain a virtual private service. As a result, many features were incorporated into the No. 4 ESS to make it function as a local office or to provide private services. This included such services as push-button (Touch-Tone) dialing, ISDN, and customer switched data (alternate voice/data service) capability.

Despite its age and limited market, the No. 4 ESS, the first of the large SPC time-division digital switches, has been and continues to be a great success. It is the principal switching system used in AT & T's toll network. It has set a trend for evolutionary development which, due to high development costs, still appears at the time of this writing to be a major direction for the industry. This progress has been accomplished with little or no fanfare. Since AT & T controls the technology used in its network, the development of No. 4 is expected to continue to evolve to meet AT & T's competitive service needs.

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CHAPTER VIII-7

THE FIRST LOCAL DIGITAL SYSTEMS IN THE UNITED STATES

1. Introduction

New ground in switching was plowed when several companies in North America, manufacturers for the independent (non-Bell) telephone industry, started to explore the application of the growing capability of microelectronics and in particular microprocessors to switching. The field trial of the first time-division digital PBX in 1974 [1] captured the imagination of some who wondered what might be a similar approach to local offices. The lecture by H.S. McDonald of Bell Laboratories at the Munich ISS 1974 [2] had also stressed many of the advantages that time-division digital switching might have in a local office. In particular he demonstrated how integrated circuits could solve the analog line to digital office interface problem.

2. The independent telephone companies ripe for new electronic switching

The motives for the efforts that sprung up in North America were due primarily to the fact that the many small independent operating companies had not yet begun to purchase electronic switching systems. Although the systems being explored were small, they included stored program control (SPC). The invention of the microprocessor brought SPC within the economic realm of these small systems. SPC and new switching network architectures were but two of the characteristics distinguishing these systems from earlier systems, such as the E10 (see Chapter VIII-4).

Furthermore, with the existence of many small central offices in the independent telephone companies, the possibilities of remote switch units were attractive. It would give these systems an opportunity to centralize their maintenance and administration at host offices. The independent telephone market was thought to be ideal not only because on the average their offices were smaller, but they also required less features and therefore would be easier to develop.

What was known as the "independent telephone industry" had its own switch manufacturers, primarily Stromberg-Carlson, ITT-North, Northern Electric, and Automatic Electric (later GTE). The latter two supplied not only their own affiliated telephone companies, viz. Bell Canada and General Telephone systems respectively, but also other independent telephone companies. The story of Northern Electric accomplishments will be covered in the next Chapter VIII-8 and General Telephone (GTE) digital switching efforts in Chapter IX-4. All of these manufacturers, except possibly the latter which, like the Bell System, already had a sizable investment in space-division electronic switching, were in the vanguard of those exploring the development of digital time-division local office switches.

3. The interface problem

One should keep in mind that for this application, in it purest form, the subscriber telephone lines/sets, drawing from 15 to 250 milliamperes with 90 volts low-frequency ringing, and the corresponding line circuits in the local central office of both electromechanical and electronic switching systems had become standard for almost a century. Now, for the first time, the technology for bringing the analog to digital interface closer to the subscriber and his terminal (telephone) appeared economically possible. It was an application that had not been explored much in depth. Many who were most enthusiastic about the robustness of integrated digital transmission and switching failed to recognized how important and difficult it would be to provide this interface [3].

The ESSEX (Chapter II-4) and PLATON (E1, forerunner of E10) (Chapter VIII-3) experiments kept the interface problem for analog lines at the trunk portion of the switch where trunk digital PCM circuits interface the digital facilities of the local office. McDonald was one of the first to describe an analog line/digital switch interface at the subscriber line circuit.

The new digital microelectronics technology also attracted new entrepreneurs to the telephone switching business and a few were brave enough to believe they could design a central office switch as well as digital PBXs. Most did not have sufficient understanding of the central office requirements which in the United States differed considerably from those of the PBXs. But with varying degrees of success some remained in business for a while.

4. BORSCHT [4]

As stated in Chapter II-3, acronyms are the bane of this industry. The term BORSCHT emerged for the circuit that provides the set of interface functions required between an analog line and a time-division digital switch. The term was first suggested in the early 1970s by J.E. Iwerson, a department head in the micro-circuit chip design department at Bell Laboratories.

BORSCHT includes the following functions:

B = Battery feed	supplying central office battery to the analog telephone line
O = Overvoltage	protection of the low energy components of the interface circuit against accidentally applied external high voltages
R = Ringing	ringing for analog telephones requires high energy levels (which cannot pass through the time-division digital network)
S = Supervision	to detect the on-hook and off-hook analog telephone conditions over lines of variable lengths and electrical conditions
C = Coding/Decoding	conversion of analog speech to digital samples, generally for a specific time-channel, and the inverse conversion of digital speech signals to analog, including the necessary filtering
H = Hybrid	conversion of the two-wire two-way analog speech transmission to separate circuits for sending and receiving the coded digital signals
T = Test	access to test the analog line and to determine if the central office circuits are in working order

There are different BORSCHT requirements for application in different countries and for various PBXs. Often, these differences confused semi-conductor manufacturers as they attempted to find a single set of chips to provide these functions.

The chip manufacturers finally settled in on some basic subsets of the functions for which the requirements at the time seemed stable [5]:

- one such subset was called SLIC, the "Subscriber Line Interface Circuit". This generally includes the B, S and H functions;
- another subset was for the C (coding/decoding) function, except for the filters. This circuit sometimes included gating functions so that, under proper control, the circuit could act as the time multiplex stage (TMS) of the time-division digital network and place the sample into an assigned time-slot.

The development of BORSCHT started about 1972 but, because of the changing technology, did not settle down for at least ten years. Initially the R and T functions required relays. Later these were replaced with high-energy semi-conductor devices.

The H (hybrid) function included a lumped impedance that was required to balance the distributed impedance of each analog line. But, unlike toll office applications where trunk circuits are designed for a constant impedance, the local office lines vary widely in impedance depending, among other things, upon the distribution facilities used and the length of each subscriber's loop. Without this balance there could be an echo. Early designs took several easy ways to overcome the echo problem. One was to insert an impedance or loss in the digital speech path. This was generally considered unacceptable because it meant that the connection quality on some calls from a local digital office would be poorer than those from an analog office. Another solution was to have a manually adjusted impedance to be set when a line is installed. But this required considerable craft labor and may not always be in step with the distribution plant as changes are made in it. The solution was to design a more complex SLIC that included an automatic or self-balancing hybrid.

Another problem encountered early in the design and introduction of local digital offices was the high quiescent (on-hook) power drain of the interface circuits. It was bad enough that the time-division switching network drained power, whether or not there were established connections, and the power for the thousands of BORSCHT circuits made the power requirements for these time-division offices an operating expense much greater than for comparable space-division offices. As a result of this revelation, the SLIC and C functions were then redesigned to minimize the constant on-hook power drain for the S function and to increase the power available to the C and H functions only when an off-hook or ringing was detected or required.

Finally, for the O (Overvoltage) function there was the sensitivity of the interface circuit to outside influences, particularly lightning. Despite the most elaborate field tests of many of the early circuits, difficulties with this design parameter plagued the system and chip manufacturers for many years.

From the above dissertation one begins to gain an appreciation that, while the switching aspects of time-division digital switches were becoming well understood, the greatest problems were in the line interface circuits. The cost of these circuits shifted the principal portion of the cost of the system from the switching network to the interface circuits. The cost of these circuits now dominated the cost of local digital switches. The solution to the above problems took time and frustrated the chip manufacturers who did not expect so many design generations before there would be some semblance of stability.

5. Early offices, a bargain

Surprisingly these problems did not delude the telephone companies who bought the first systems. They tolerated these difficulties and their multiple solutions. The principal reason was that the systems were sold far below cost at a price that gave local digital switching much notoriety.

Most of the systems described below were unprofitable for three to four years after they were introduced initially. During this early period the manufacturers charged their loss as an entry fee to gain experience in this new world of local digital switching.

This situation made it difficult for AT&T and GTE. Under heavy regulatory constraints, they could not at that time justify the development of new systems that were known to cost more than the space-division electronic systems then being deployed. Many State regulators and the FCC requested an explanation of this situation and wondered why these large companies were not taking advantage of buying these relatively inexpensive system bargains.

Eventually the Bell and General Telephone companies succumbed and purchased some of these systems after having the designs modified to meet the requirements for their applications. The

systems adapted and purchased were mostly those of Northern Electric, later to be known as Northern Telecom Inc. (see Chapter VIII-8).

6. Stromberg Carlson – DCO (System Century)

6.1. Who is Stromberg Carlson?

The Stromberg Carlson Co. has been a supplier of switchboards and switching systems to the United States independent telephone industry since 1894 (see Volume I – Chapter III-3). With the advent of electronic switching the company was in the forefront in advancing this technology to the independent telephone companies. For example, as early as 1962 they brought to market several analog time-division products, a PBX, a CDO, and a military switch. Also in the early 1970s they developed a digital switch for a new data network called DATRAN that went into service in January 1975.

In the mid-1960s, Stromberg Carlson became a subsidiary of General Dynamics. Stromberg had developed and successfully marketed electronic space-division PBXs called "Crossreed". The new affiliation brought a significant infusion of capital and development money. They started to develop a digital time-division central office switching system. This development was moved to Sanford, Florida. They spent over $50 million developing the system called "Century" before the company was again sold in 1982 to the Plessey Company of the United Kingdom.

As indicated above, early entrants in this market did so because they believed in the future of digital micro-electronics and not because they were expecting an immediate economic advantage in telecommunications. In early 1986, four years after Plessey took over and 9 years after the Century system had been first introduced, the product line became profitable. By that time an additional $30 million had been spent developing the system.

Plessey was one the major contributors to the UK System X (see Chapter IX-5). Over the years since Plessey acquired the company, there have been repeated efforts by managers brought from the UK by Plessey and their successors [1)] to introduce System X technology into System Century. So far this has not succeeded and System Century has proceeded to slowly evolve to fill a niche in the "small system" market in the United States.

6.2. System Century [6]

The first local digital switching system with SPC ready to be demonstrated was by the Stromberg Carlson Co., then of Rochester, NY and Sanford, Florida. They called their switch family "System Century" and coded the system DCO (Digital Central Office).

An historic first SPC local time-division office cutover was in Richmond Hills, Georgia, on July 16, 1977. It was a 500 line unit.

The initial DCO system came in three version sizes, of up to 2,000 lines. The system used duplicated DEC microprocessors coded PDP 11 as telephone processors and an extra one for maintenance. Traffic capacity was advertised as 24,000 BHCAs.

The line interface cards serving one line contained four chips and three relays. The switch used a simple switching network that did not stress the technology. The port (line side) unit served 32 lines or trunks with 32 time-slots at a 2.044 Mbit/s pulse rate. Four of these port-units were multiplexed to 128 time-slots that were then, as in the E10 switch, converted to parallel 8 bit words on 128 time slots for a pulse rate of about 8 Mbit/s.

6.3. System Variations and Growth

Conservatism was the principal characteristic of this manufacturer's approach to meet the needs

[1)] A joint venture, called GPT, of the British Plessey and General Electric Ltd companies was formed in 1987 for the continuing development and marketing of System X. Stromberg Carlson became part of this new switching joint venture.

In 1989 Siemens acquired a portion of the GPT thereby acquiring an interest in Stromberg Carlson with whom they compete in the United States with their EWSD system.

of the independent telephone market. As the system gained credibility in this market, its size was gradually increased in steps, first to 7,000 lines, then to 25,000 and eventually (1986) to 32,000 lines (max. 6,100 Erlangs) and to 70,000 lines with as many as 90 remotes. The controls were also gradually improved to 114,000 BHCAs.

Remote network switches are capable of serving a maximum of 10,000 lines with tandem operation and "stand alone" capability. Remote line groups may subtend the remote network switches, making a three-stage cascade of remote switching before reaching the host office.

As with most manufacturers there has been several generations of the line circuit cards. Most of these efforts were to reduce the number of chips, eliminate the relays, and until recently to place more lines on a printed wiring board. The trend is now returning to individual but smaller line circuit cards.

Smaller offices (DCO-S) were also repackaged to make for units of 360, 720, to 1060 lines, all with the ability to support remote units as well. Other units were developed for small tandem, cellular mobile, PBX, and even international gateway offices.

Foreign sales were made in the Western world, from Samoa to Canada and to Puerto Rico. A version (DCO-CS) of the switch was sold to toll resellers and small interexchange carriers in the United States.

The 23 offices in service by year-end 1979 increased by the end of 1984 to more than 500 offices and 300 remotes, serving more than one million lines. By the end of 1988 more than 2 million lines and 1000 offices and 1000 remotes were in service.

In 1986 a first sale was made to a Bell (South Central) operating company. This company in many respects reflected the demographics of an independent company with many small offices. New features were developed specifically for this market, a process that is continuing. After trials, significant purchases were made: 150,000 lines in 1988 and 450,000 lines for the 1989–90 time frame.

With success within this segment of the former Bell market, the company has embarked upon a more extensive development program, gradually expanding the system's capabilities to include features that it believes will further expand its application into a larger RBOCs market. Similar features were also developed for the independent market. With perseverance Stromberg Carlson has demonstrated how system design evolution, a slogan being used by many manufacturers for the 1990s, works. The success of this approach depends a great deal upon the quality and size of the foundation. It remains to be seen how much further systems of this generation may be extended. Slow but sure evolution is much like the hare and tortoise when comparing Stromberg-Carlson's success with that of the big players AT&T and Northern Telecom.

With development being expanded to include sophisticated features such as CENTREX, ISDN, and signaling system No. 7, Plessey and later GPT continue to examine their investment in Stromberg. Their decision will determine whether the original System CENTURY has gone about as far as it can go and whether its place in the market might be better served by bringing to America System X or now System EWSD, now that Siemens is part of GPT (formerly Plessey).

7. Vidar – Systems IMA/ITS4 [7]

Vidar started life as a transmission system manufacturing company which had been purchased by the "Continental" independent operating company. In 1975 it became a division of the TRW company, a company known mostly for its contributions to the space program. "Continental" continued to be its major customer.

The only previous activity Vidar had in switching was the development of a message register recording system. It was quite natural for them in 1973 to decide to develop a time-division digital switch to interface with their successful line production of digital transmission systems. Their approach was primarily to emphasize integrated digital transmission and switching. Their anticipated market was the many small offices of Continental Telephone, many of these offices being already served with digital trunk facilities.

Another factor began influencing the deployment of the tandem or toll offices by independent telephone companies at about this time. The formula for dividing the revenues from independent-originated toll calls into the nationwide network was changed and became more favorable for independent companies that made additional investments in a certain kind of plant. As a result, many companies installed their own tandem switching centers where they not only switched their toll calls but also recorded the billing data for automatic message accounting.

The Vidar system then had two purposes: one was to provide digital toll switching; the second, to record messages for billing purposes. The initial name given to the system was "Integrated Message Accounting", so the code for the system was "IMA".

The system was modest in its capability, serving a maximum of 1536 trunks and service circuits (64 T1 lines). This was deemed adequate for most of this market. The microprocessor control was duplicated, with a capacity of 10,000 BHCAs. It included a tape drive for recording the call details. The 8 bit speech samples were switched on a parallel basis with an added bit as a parity check. There were 384 time-slots, making the clock rate 3.088 MHz.

Earlier experiments and field trials had used the basic switching elements in the space-time-space (S-T-S) mode. The IMA systems was the first commercial system to use the reverse order of these elements.

The first office was installed in Ridgecrest, California, and cut over on March 26, 1976. It served a local office in China Lake, California, over digital facilities. As mentioned in Chapter VIII-6, it was the first SPC time-division switch interconnecting digital facilities.

The development of the system continued with a combined remote-switching and subscriber-line-carrier terminal, serving PCM lines on 48 time-channels. The system evolved into a product line and its name was changed to "Integrated Transmission and Switching", coded ITS4/5, for local and tandem offices respectively. Eventually, slightly less than 200 switches were placed in service, serving about 300,000 lines. The product line continued until 1983 when further development and manufacture were discontinued.

8. ITT/North – DSS/1210 [8]

North Electric was a famous name in telephone switching manufacturing for independent companies [2] when, in 1963, it was acquired by the large independent operating company, United Telephone. This operating company controlled North Electric until 1972 when it became generally accepted that electronic switching was the coming technology and it was expensive to support its development. At that time North Electric was sold to ITT. ITT already owned facilities in Milan, Tennessee, where they designed adjuncts for switching systems such as automatic line identifiers and touch-tone service equipment. The ITT acquisition gave North Electric the expanded capability to develop electronic switching systems.

At that time North had in its employ many leaders in the field of switching. Included were C.G. Svala, N.J. Skaperda, W.H.C. Higgins and H.E. Vaughan, the latter two having retired from Bell Laboratories.

The North-ITT system was initially called "Digital Switching System" (DSS) but after ITT started their System 12 series (see Chapter IX-7), it was coded the "1210".

The system was developed a little later than the DCO of Stromberg-Carlson and therefore the technology was a bit newer. For example, the initial line card, called a "quad", contained four subscriber line circuits with only 2 relays per line. The switching network initially supported a maximum of 12,000 lines with line switches serving a maximum of 320 lines. The line switches could

[2] North Electric company has a long history. Its name is not due to a geographical connotation but to the name of its 1910 founding father, Charles E. North, an outstandingly able engineer and a switching pioneer. For the history of the company which has passed several times from the hands of one company to another, see Volume I, pp. 81, 112 and 430.

be remoted, up to 50 miles. As in most of these so-called small office developments, the line size was increased to 26,000 lines (DSS1). There also was a containerized version and a DSS3 32,000 trunk tandem/toll office.

A separate central processor, known as the OMNI V, was developed using the experience North had gained with the ETS4 (an Americanized version of the AKE13 system – see Chapter V-10) switch development.

The first office of 924 lines was cut into service in Emlenton, Pennsylvania, on September 23, 1978. Only one trial sales was made to the Bell System and systems were exported to Taiwan and the Philippines. A cellular radio version was also developed.

By the end of 1986, over 1 million lines were in service for about 2000 offices. Many of these offices were purchased by United Telephone, the previous owner of North. As planned, they met a need for larger offices than those for which Stromberg-Carlson or Vidar had aimed.

Only 96,000 lines were made in 1986. ITT North became affiliated with Alcatel when ITT sold its switching interests in 1987. ITT claims that the total development for this system was close to $500 million over 10 years.

9. Other American attempts at local digital switching

So far we have described three first generation American digital local switches. The DMS family of Northern Telecom covered in the next Chapter is an important part of this generation.

But there have been other less successful or history making systems on the American scene. For completeness these are mentioned below.

It is interesting to note that many of these less successful systems leave little in the way of a publication trail, particularly in those periodicals most noted in the industry for disclosures of new switching developments.

9.1. Nippon Electric (NEC) – NEAX61 [9]

The NEAX61, a system that has been successful in world markets, started in the United States with a first cutover on May 5, 1979, in Manteca, California. Much of its initial software development work was done in the United States.

The system was characterized by the use of pnpn crosspoints for a space-division switch in the line concentrator stage. It was designed for central multi-processor operation. The system evolved over its now 10 years of existence and, with its worldwide applications, has more varieties and versions than most systems. There have been several generations of equipment (E,F,K) and software design.

A proposed application of the NEAX61E is an adjunct to space-division systems to provide ISDN [10]. Digital subscriber lines terminate on a small NEAX61E switch interconnected with the space-division system. Calls to and from these lines are then double switched or screened, with ISDN calls being served by the NEAX61E adjunct switch. The principal sales thrust for this approach was the United States where there were many space-division systems. While a small number of trial installations were scheduled and undertaken the results are not conclusive as of this writing.

As of early 1987 there were more than 5 million lines of NEAX61 equipment in service in 37 countries, with about 10 million additional lines on order [3]. However, the United States market represented less than 10% of the total sales.

9.2. Fujitsu – FOCUS 5

Fujitsu, another Japanese manufacturer, developed in the early 1980s a system called FOCUS 5 for the American market. It was a system intended for the small offices of "Independent companies", with a capacity limited to 12,000 lines. Two offices were installed but a decision to abort the market was made shortly before the offices were scheduled for cutover in March 1982.

[3] See Chapter VIII-9 for more information on the NEAX61 worldwide.

After introducing another system, FETEX 150, into other markets (see Chapter VIII-9), Fujitsu has recently (1989) announced a reentry into the United States market with a version of this system.

9.3. ALCATEL – TSS5 / E10S / E10-FIVE

This system, with various codes, was an Americanized version of the E10S developed in France by CIT-Alcatel from a stored program controlled (SPC) version of the E10 system (see Chapter VIII-4). In France, the E10S was introduced for special applications such as telematics and cellular mobile radio.

As a local system in the United States, about 100 switches of this Americanized version, most generally known under the code name "E10 5" [4)], were placed into service. They totalled not more than 150,000 lines. Their American market was for very small independent offices, although a remote switch was also under development.

Lynch Communication Systems, Inc., a successful manufacturer of transmission and line concentrator equipment for the independent industry, had started to design a switch coded LCS with a distributing frame manufacturer, Cook Electric Co. and the assistance of college professors. Alcatel purchased 25% of the Lynch company with the expectation that their two United States efforts might be combined, but this merger was unsuccessful.

9.4. REDCOM – MDU [11]

Redcom of Victor, NY, is a small company started in 1978 by K. Gueldenpfenning. He had a unique idea that, when developed, found a niche primarily in the North American very-small office market. This market for offices of less than 1200 lines was largely financed by the Rural Electrification Administration (REA) from whom Redcom received an acceptance rating.

Redcom developed a small basic 384-port time-division digital unit that could be used to serve lines or trunks. The units may be stacked together to form larger systems, called MDXs. Initially the systems were limited to 1200 ports with the MDX-384, but more recently the MDX-10K permits expansion to 10,000 ports. Also versions of the units have been sold for private network use, for PBXs and Automatic Call Distributors (ACDs).

The system has been sold not only in the United States, particularly Alaska, but also in Hong Kong, People's Republic of China, Philippines, Taiwan, and even the remote reaches of Canada.

9.5. Digital Switches That Turned ... The Grass is Always Greener in a Different Market

It has not been unusual for those with digital PBX products that did not sell well to attempt to convert them to central office switches to expand the market. The Canadian company, MITEL, had a digital PBX (SX2000) with rather slow sales. When Mitel received financial support from British Telecom who bought 51% of the company, they projected a product called CX5000 for a central office version. Like most who have tried this approach, they failed.

An American company called Digital Switch Corporation started in McLean, Virginia, to develop a local switch coded DSC1. After spending considerable resources, they dropped the local switch in favor of a tandem switch. They moved to Richardson, Texas (the site of many embryonic switching developments in the United States). Developing tandem and toll switches, coded DEX, primarily for the interexchange and resale carriers, they carved out a niche in the market. This has led to products such as signal transfer points and digital crossconnect switches. These products have been successful enough for them to embark on later generation switches.

DSC Corp. could not get the local digital fever out of their blood and, after their success with tandem switches, went to a second try. The

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[4)] The suffix "5" following the trade-mark E10 in the Americanized version of the E10 "S" was both an alliteration of the typographic character "S" and an indication that the target market of the E105 was for "class 5" offices in the American hierarchy of switching offices.

company president announced prematurely that, having developed a successful tandem switch, DSC Corp. had completed 80% of the development of a local switch.

Motorola had needs for a switch for its cellular mobile radio system. This switch development was called the "EMX". Motorola claimed to have sold the switch not only in the United States but also in Austria. Later it teamed up with DSC Corp. which produced for them cellular switches, always marketed with the EMX code.

Collins Radio Corp. of Cedar Rapids, Iowa, had a leader, A.A. Collins, a person much interested in digital switching [3]. As a result they started to develop tandem switches, coded DTS, to compliment their radio networks. The company became a subsidiary of the Rockwell International Corp. This company also acquired WESCOM, a manufacturer of digital transmission systems and PBXs. While the digital tandem and PBX switches were not successful, a very successful digital automatic call distributor (ACD), called "GALAXY" and coded "GVS", did emerge from these companies and was no doubt influenced by the earlier work on digital switching.

9.7. Miscellany

While discussing the early days of time-division digital, one should take note of another type of switch that gained much popularity during the 1980s. It is known by various trade names; more generically, it is called the "Digital Access and Cross Connect Switch" or DACS. It was first developed by AT&T in the later 1970s with the first installation in service in 1981.

The purpose of DACS was to permit the switching of digital transmission lines (such as T1s) so the particular channels could be moved to the same or different-time slots in different digital lines. Initially, it was a facilities switch for long-term mixing of T1 lines. Later, using computers under telephone company or customer control, it became part of various service offerings, including higher digital line rates and subrate multiplexing.

The British Marconi company also pioneered in DACS with a system called ACE. Many other companies, some principally in the digital transmission field, have since brought out successful digital cross-connect switch products.

The Marconi company in Canada was also a pioneer in time-division digital telex systems. Siemens later had products of this type.

The military forces in the United States and NATO were quite anxious to convert their field communications to digital and displayed a great interest in time-division digital switching [12]. As early as the Paris 1966 ISS, a representative of the American military forces presented a paper on developments using time-division switching for either PAM or PCM [13].

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CHAPTER VIII-8

CANADA: THE DMS FAMILY

1. Northern Electric Co. needs a new system

Chapter V-4 described the success Northern Electric Co. (NE) of Canada had with the production and marketing of the space-division SPC systems, SP1 and TOPS, which were developed by its research and development subsidiary, Bell Northern Research (BNR) [1)], during the late 1960s and in-service by 1971. NE also had a very successful analog (PAM) time-division switching PBX, the SG1, of which over 7,000 were sold.

In the 1970s, switching technology was moving rapidly. BNR was faced with the need to update the speech path device in the SP1 system to replace its mini-crossbar switches. By early 1975, a task force with representatives from Northern Telecom, BNR, and Bell Canada was appointed to develop strategies to introduce a complete line of central office switching systems. Instead of proceeding with the obvious development alternatives for the SP1 system the task force proposed a bold departure.

D.A. Chisholm and C. Denis Hall, President and Vice-President respectively of BNR, proposed to their management to develop a series of time-division digital switching products for the local plant. They had already had a measure of success with a time-division digital PBX, the SL1, which started to be developed in 1974 and was operational in 1975 [1]. A digital packet switching system, the SL10, designed for DataPAC service in Canada, had been field tested in 1976 [2] [2)].

Development started in 1975 on a small digital multiplex transmission system for subscriber distribution plant known as the DMS1, the "digital multiplex system". From this development much was learned about the analog subscriber line interface and digital transmission technologies. The first DMS1 cutovers took place in April 1977 in Canada and the United States [4].

Putting together a team of engineers experienced with these digital developments, BNR set out in 1976 to develop *a small central office* switching system that they called *the DMS10* [5]. The DMS1 and DMS10 developments concentrated on the use of integrated circuits and were among the firsts to use microprocessors.

Perhaps overshadowing the actual development of these systems was the announcement in early 1976 of the sales sendoff that the entire product line received. The thrust of NE's product development and marketing efforts were given the name "Digital World" (see also the Canada keynote paper at the Paris 1979 ISS: "Canada goes digital" [6]). In North America, it was the beginning of the "hype" which has accompanied time-division digital switching for more than the past decade.

1) BNR was started in January 1971 (see insert in Telesis, No. 1, 1981). It was formerly called Northern Electric Labs. BNR was purposely patterned after Bell Laboratories by its first president, Donald A. Chisholm, who had previous been associated with Bell Labs.

2) In 1980, the SL10 was introduced into Europe, in particular for use in the West German (DBP) packet network [3].

The DMS10 was their first central office switching product in digital technique. It used a duplex version of the processor from the SL1 PBX and an interface circuit that had been developed for analog subscriber lines.

Its first cutover was a 400 line DMS10 office installed in Fort White, Florida. Since it served Disney World, its cutover on October 23, 1977, was carried out with much fanfare. In October 1978, Bell Canada cut into service its first digital switching machine, as a DMS10 office, 1900 lines (designed to be extended to 6000 lines), serving Embrun, a small community located 40 km from Ottawa.

2. Invading the United States...

It is significant to note that this first installation was not in Canada but in the United States. Besides being a technological accomplishment, the DMS10 development also included an audacious plan for marketing the system. Northern Electric had recognized that at that time the largest market for new switching systems was among the United States independent telephone companies, which had been slow to embrace electronic switching [3].

Bringing the DMS system to the United States was not NE's first switching entry into this American market. For electromechanical switching offices in the 1960s and early 1970s, NE had sold its version of No. 5 Crossbar to independents through Stromberg Carlson. It also had a very small crossbar system called SA1 which it had sold earlier to some Bell Operating Companies (BOCs).

Besides having a good marketing strategy, BNR/NE recognized where the major costs lay in these small digital switching systems. It was in the BORSCHT circuit (see Chapter VIII-7). At the time NE owned a semi-conductor manufacturing company. NE's management understood that the technologies that would make these systems economical were in sight for the future but were not available currently. This management was willing to set its sights on this distant target and recognize that the products would not be economically viable in the immediate future. This also meant that the prices for these systems were set with market entry in mind, rather than initial profit. In fact, the DMS 10 product line was not considered profitable until 1985.

3. The DMS10 system [7]

As previously mentioned, the DMS10 evolved from the SL1 PBX with the addition of duplicated processors and, of course, the necessary software for the central office application. There were four subscriber lines per printed wire card. The switching network used 30 time-slot buses, 8 bit serial, with only a T-T configuration. This network provided for about 1K Erlang of traffic capacity. The control provided 12.5 BHCAs, and was programmed in a proprietary high level language.

4. Expanding the DMS10 system and its market [8]

Of course, the DMS10 was primarily sold in Canada to BNR/NE's parent, Bell Canada.

With sales success in this area, NE started looking for new markets. It established production facilities in the United States in Raleigh, North Carolina, and even incorporated in the United States, changing its name to Northern Telecommunications Inc. (hereafter "NTI"). As early as 1975, it incorporated BNR and opened a unit in Mountain View, California. Later, BNR established a larger laboratory in Raleigh, North Carolina.

The next market NTI recognized to be conquered was the big AT&T and its Bell Operating Companies (BOCs). For them, AT&T had

[3] As described in Chapter VIII-7, BNR and Northern Electric were not the only ones to recognize the potentiality of this market. Regular suppliers in this market, i.e. North Electric Co. (by then an ITT subsidiary) and Stromberg-Carlson, were also developing small time-division digital switching systems. Stromberg-Carlson actually had its system in service before the first DMS10.

only the space-division small SPC systems, the No. 2 and 3 ESSs. Regulators were asking why independent telephone companies, but not the BOCs, were buying time-division digital systems.

AT&T evaluated the DMS10 system, asked for and obtained design changes. In 1980, AT&T informed the BOCs that, if they had a need for digital switching in small offices, a version of the DMS10 developed to AT&T requirements could be installed. The first DMS10 BOC office was installed in Union, Kentucky, in January 1980.

By 1983, the BOCs had in service more than 100 DMS10 offices with a total of more than 250,000 lines. At the time, this represented about 15% of total sales of the system.

The NTI marketing strategy had paid off and at last this important market had been penetrated. Eventually this benefited not only NTI's other products, but other suppliers as well as, by showing the way. In the process, both NTI and the BOCs learned a lot about what it takes to satisfy customers who had a long tradition in the installation, training and operating of central offices.

It is important to understand that NTI was the first manufacturer of central office switching equipment willing to change its designs, initially software for the most part, to meet the requirements of the Bell System market. Today (1988) many off-shore manufacturers are attempting to emulate this market entry strategy in the United States at a high development cost of at least US$ 100 million per year [4)].

[4)] Several other manufacturers have attempted to take this route but have found it too expensive for them. Companies such as ITT, Fujitsu, Lynch, Digital Switch, and others have turned away from this market (see Chapter VIII-7). The reason generally given has been the high ongoing costs of system development, particularly for software. But hidden in these decisions are the increasingly sophisticated requirements of the larger administrations in the United States. Bell Communications Research issues and updates a set of 33 volumes stating these requirements for the benefit of those attempting to develop switching systems for sale to the RBOCs. These are known as the "Intra-Lata Switching System General Requirements" (LSSGR). They include at least 1000 services and features that a local switching system should include for application in the general RBOC market.

5. DMS10 deployment

By the end of 1988 more than 2000 DMS10 offices, including at least 300 remote offices, were in service in 20 countries, serving over 3 million lines. Among these countries: Belize, the Caribbean Islands, China (People's Republic), South Korea, Micronesia and Peru.

The DMS10 system originally had a maximum capacity of 8000 lines. Following a pattern that is usually successful in this industry, both smaller and larger system designs were developed. The system now extends to 10,000 lines in a "series 400" version, and a DMS10S version in a single cabinet was developed to serve 450 lines. There also exists a container transportable version for emergency use, serving up to 10,000 lines. An office arrangement, known as Satellite Switching Offices, the DMS10-SSO, with a configuration in clusters, can accommodate from 17,500 to 50,000 lines, these clusters being intended primarily for the centralization of administration and maintenance functions.

NTI was the first foreign manufacturer to sell central office switches to the Japanese market. Called the "KS2", the system is a version of the DMS10 that serves 2400 lines and/or 2000 trunks [9]. It includes two different line card designs. The first of these switches was cut over on March 17, 1988. It is expected that 100 switches of this DMS10 version, totalling 1.5 million lines, will be delivered by 1993.

6. Launch of the larger DMS family – the DMS200

It was recognized early on by BNR that the small office DMS10 system was only a market entry product.

The firm did not believe that this product would always remain popular in the market. The principal owner of NTI was Bell Canada. NTI postulated requirements that larger offices were needed in Canada since Bell Canada would not wish to continue with space-division systems. By 1976 it was also obvious that, if the North American independent market was buying the

smaller digital systems offered by NTI, ITT/North and Stromberg-Carlson, the Bell System and its BOCs could be an even larger market. AT&T and its Western Electric subsidiary, while leading in time-division digital systems with their No. 4 ESS transit office, were not yet about to enter the time-division local office competition [5].

With the DMS10 experience well under way, BNR took then a much bolder step. It commenced development work aimed at a family of larger switching systems [10,11], one that, if successful, would have a tremendous payoff. The keystone, as for many large time-division digital switching system developments, was the central distribution switching network.

This switching network was the center piece for *a tandem or transit office* and *was called the DMS200* [12]. The basic switch elements in this network are a series of four time-space modules under microprocessor control, that operate with 32 time-slot buses, of 10 bits parallel. The modules of the switching network were not of the "reciprocal" structure and therefore, as it grew, like many space-division networks, it required rearrangement of the junctors between network modules. [6]

The first milestone in the DMS100/200 development program was the successful cutover of the toll DMS200 machine in the Bell Canada's Ottawa O'Connor exchange in January 1979 [10].

A recent development has been the sale of a DMS300 international gateway to British Telecom after NTI acquired a 27.5% interest in the former ITT subsidiary, Standard Telephones, STC.

[5] As discussed in Chapter IX-3, section 1, this may have had a hidden advantage since the later AT&T and Western Electric entered the market, the more advanced were the technology and architecture and readiness for new services and features.

[6] The switching network of a large DMS100 can consist of as many as 64 modules.

7. DMS100, the large local switch [11]

7.1. With the early recognition that the capacity of the DMS10 was insufficient for use in large metropolitan environments, the NTI development of a large local office centered around the switching network of the DMS200. The local office target was a maximum of 60,000 terminations, a capacity of 22,000 Erlangs, and a matching loss of less than 0.5%. The switching network was developed to be the central subsystem for an entire product line, called the DMS Family or DMS100F. While there have been indications that a new switching network is to be part of the system evolution, to this last writing (mid-1989), it had not yet been announced.

7.2. For the *local office version* of the system, *called the DMS100,* peripheral line-interface BORSCHT circuits were developed [13]. They were added in modules that included time-slot interchangers. This portion of the system had an equipment arrangement that was unique for the first generation of digital switches. Each line circuit is mounted on a separate "daughter" printed wiring card. This line-card is plugged into a "mother"-board that mounts 64 line-cards [7]. Besides the maintenance advantages of this approach, the individual cards could be different for each line, in order to match the changing service needs of the subscribers. NTI looked

[7] In most systems, large uniform-size printed wire boards are used to obtain equipment economies. When used for the line (or trunk) circuits, it has been the practice of most manufacturers to use the available board space for as many line circuits as possible. As technology has improved, the number of line circuits per board has increased to as many as 16. However, should a particular line circuit develop a component failure, the entire board must be removed and replaced. If this is being done while other lines on the board are active, service to these lines is interrupted, deteriorating the quality of service. The alternative is to delay repairs until all lines are quiescent. Line-cards are required in very large quantities! Eventually, both the DMS10 and DMS100 used the same automatically produced line-cards. NTI's production through 1988 amounted to over 20 million line-cards.

forward to when the entire line-card might be replaced by an integrated circuit chip. They did produce experimental models on a single silicon wafer with most of the required variety of chips on it. As in most systems, the line-card was improved over the years, mostly to reduce costs. In this respect, the presence of individual line-cards proved it advantageous and easier to implement [14].

7.3. The *initial* architecture of the system was principally of the central control type [8]. Very little call processing was performed in peripherals, called line modules, which contained an 8085 microprocessor. The line module contained an S-stage with a maximum of 120 10-bit time-slots, and could serve up to 640 lines. There was a separate central message unit to reach the switching network for control.

The central processor was initially developed as an integrated circuit version of the control used in the SP-1E system and was called the "NT40". It was programmed in the NTI high level language, called PROTEL, which is a block-structured, "strongly typed" language.

7.4. The library of software programs for the DMS100 Family was extended over the years and became very large, totalling more than five million lines of code in 1987. Software used for a DMS100 may also be very large: as an example, for a typical DMS100 exchange of the last generation and configured to include the business services package, it may consist of as many as two-and-a-half million code lines [15,16].

NTI introduced a policy of leasing the software to "telephone operators" on a right-to-use basis. The individual programs were called Batch Change Supplements or BCSs, a term that gained considerable recognition among NTI's customers.

7.5. The large office family was even more successful than the DMS10 product. Although the first DMS200 office was not placed in service until January 1979, the product line was profitable by 1984. The first DMS100 local office was placed in service in Ottawa, Canada, in September 1979. By the end of 1988, there were 2070 local offices in service with over 26 million lines in 28 countries, 66% of them being in the United States.

8. Success in the United States markets

While the DMS10 was earlier accepted by AT&T and its BOCs before the 1984 AT&T divestiture, and many were also sold after divestiture, the DMS100/200 family became even more important to the success of NTI in the United States as a major supplier of central office switches.

In 1982, after extensive technical and quality evaluation of the DMS200 and prior to the divestiture, AT&T authorized purchase of the system for applications in their network where a time-division digital system smaller than the No. 4 ESS was indicated as being more economical. The first installation of the DMS200 in the AT&T network was in Chico, California, in March 1983.

AT&T then started working with NTI to adopt the DMS100 for possible purchase by the BOCs. After the addition of many services and features to the system program, studies of the system were completed and AT&T sent a letter to the BOCs in September 1983 indicating their suitability for general local application. Thus, three months before the divestiture, AT&T indicated that a version of the DMS100 system had been approved for use by the BOCs.

Of course, by this time and somewhat belatedly, AT&T Bell Laboratories were developing their own local digital time-division system, the No. 5 ESS. As a result of the AT&T divestiture, the "RBOCs", which were the Regional holding companies or foster parents of the Bell System Operating Companies (BOCs), were expected to look for one or another switching sys-

[8] Eventually, with its evolution over the years, the DMS100 architecture became what NTI now advocates as a distributed structure. A large number of peripheral modules, microprocessor-controlled, carry out the routine telephony tasks. Besides the peripheral modules, processors are located in the central control, in the switching network modules, and in input/output controllers.

tem as alternatives to those they had previously purchased under monopoly agreements from Western Electric (the manufacturing arm of AT & T).

NTI had the foresight to move into this market. It was ahead of most foreign competition, and had already learned to work with and cater to the BOC requirements. This aspect of competition in the United States was not well understood by many switching manufacturers who also thought they saw opportunities in this new market opening. They were used to selling mostly uniform products with a minimum of changes to meet the requirements of particular customers. They found out with difficulty and at great expense that switching systems could not then be sold into the United States market as commodities.

NTI established departments at BNR specifically engaged in the development of services and features to meet the RBOC requirements. Foremost among these features, it was to provide subscribers with the so-called "equal access" provision imposed by the AT & T divestiture, i. e. the automatic access to the interexchange carrier of the subscriber's choice [17] [9].

AT & T, with its No. 5 ESS (see Chapter IX-3), did not catch up with the head start of NTI until 1986 when, for the first time, the RBOCs purchased more No. 5 ESSs than DMS100s. Even then, some of the RBOCs continued to prefer the NTI products. With a large amount of automated production, price competition and quality became the major bases for the RBOC's product evaluation, comparison and selection.

9. The DMS100 family evolution [18,19]

In 1983, NTI introduced into the DMS100 a service it called the "Integrated Business Network (IBN)", as an alternative to Centrex service for private networks [20]. Centrex (see Chapter V-1) was a popular BOCs' service that was offered in their space-division systems. To provide uniformity of service it was necessary that the DMS100 be programmed to offer Centrex service [10]. This resulted with the "first in the world" Centrex service available on a digital switching system. To emphasize its uniqueness, the system was given the name "Meridian Digital Centrex". By year-end 1988, more than three million lines of this type were in service. One of the largest Centrex installations at that time was the DMS100 office (with Supercore, see 10.2 below) in Sacramento, California, with 44,000 lines. Availability of this service feature also helped NTI to capture a foreign sale for the Mercury network in the United Kingdom. Eventually, much of the Digital World product line was renamed Meridian.

The DMS200 system was arranged for the RBOCs as access tandems to interchange traffic with interexchange carriers that did not have trunks to all end offices. Also with divestiture the RBOCs lost most of their operator switching systems (TSPS) (see Chapter V-1). NTI adapted its TOPS (Traffic Operator Position System) (see Chapter V-4) digital acces for use with the access tandem offices. There was also a combined local/tandem system, the DMS100/200.

The DMS100 product family was further extended with two versions:

- The first of these versions was the *DMS300*, developed as *an international gateway* [21]. Its first cutover was in Canada in August 1981 in Montreal, Quebec. In the United States it was sold to COMSAT and to one of the interexchange carriers (US Sprint). In Japan it was sold to the new non-NTT toll carriers. It was also sold in Australia.
- The second version was the *DMS250* [22], *a tandem or toll switch* for interexchange carriers with heavy traffic. Development and some production of this system was carried out in a

[9] AT&T was obliged to design the equal access feature into all of its space-division SPC systems except for the No. 3 ESS. Somewhat later, NTI provided equal access for DMS10 offices.

[10] This illustrates why it is difficult for competitive innovation to be successful, since telephone administrations with many offices wish to have this so-called "transparency" regardless of which vendor's systems they purchase.

separate facility in Richardson, Texas. The first switches of this type were cut over in 1982 as part of IBM's short-lived excursion into the satellite communications business, SBS. For NTI, this turned out to be an especially successful speciality switch, with sales in the United States to many interexchange carriers other than AT&T.

Later, NTI/BNR developed versions of the DMS100/200 system for large PBXs (SL100) [23], for military networks (SCOPE-DIAL), and for cellular mobile switching offices (DMS-MTX) [24], the latter in cooperation with General Electric in the USA.

A characteristic of this family was the use of the same basic switching network. While this network and the periphery had their limitations, they nevertheless were and remained the heart of the family.

TOPS was added to DMS250, and newer developments applied to the all items of the family. It was not unusual to find series of different DMS250s such as the 250C, 250M, 250IBN, and DMS250/300 for special orders.

International markets, where competition was more formidable, did not develop as easily as those in North America and the Caribbean area. The system was licensed for production in Turkey by NETAS, in Israel by Tadiran, and in Austria by Kapsch and Schrack. Sales have also been made in China (People's Rep.).

A recent development has been the sale of a DMS300 international gateway to British Telecom after NTI acquired a 27.5% interest in the former ITT subsidiary, Standard Telephones, STC.

10. The DMS100 system architecture evolves [11)]

10.1. Remotes

It should be remembered that the first successful NTI product was the DMS1 subscriber line multiplexer [4], which was actually a remote line concentrator. Its purpose was to bring as many as 256 subscriber lines into a host switch by using 48 digital transmission channels. A version of the DMS1, called a remote equipment module (REM), was used with the DMS10, but not until 1981.

Early in the development of the DMS100, it was assumed that the DMS1 would eventually interface directly with the switch without a central office terminal. Furthermore, when greater capacity and feature-rich remotes were required, the DMS10 system would be employed as a remote. While this came to pass rather slowly (with a development known as the DMS1-Urban [25]), a remote line module (RLM), similar to the line modules used in the central office, was developed. The delay in bringing the remote switching to market may have been endemic to the DMS100 system and NTI's approach to the market. The RLM was rather late among the system developments, with the first one being cut over in 1981.

Eventually, many larger remote switches, some including stand-alone and intra remote-switch options, were made available [10] as follows:

- RLCM (remote line controller) – 640 lines
- RSLE (remote switch line equipment) – 1024 lines
- RSC (remote switching center) – 5760 lines
- LBR (large business remote) – 30K lines

The lag in making these products available might be attributed to the revision of the system periphery to accommodate new services such as ISDN and a deliberate delay to better understand the market needs [26]. One important evolutionary change in the periphery has been to divide the line group controller into a line-concentrating module and a line-trunk controller.

From this better market understanding, the use of cluster techniques has evolved, bringing together several remote switches at the same location with switching between them and use of a remote cluster controller (RCC), an NT40.

10.2. SuperNode

The initial capacity of the control was advertised to be as high as 350,000 BHCAs for the

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[11)] While this section discusses the evolution of the DMS100 family, many similar modifications have been or are being planned for the DMS10 product lines.

DMS200 (toll), and 300,000 BHCAs for the DMS100 (local, see below). As the RBOCs in particular expanded their use of the DMS family, they found that the control capacity of the original NT40 processor was inadequate for many of the Centrex installations which generally have higher calling rate lines. Over several years, the capacity of the control was gradually increased. The first and simplest way was to change the processor clock rate from 36 MHz to 40 MHz. Afterwards, more powerful Motoroloa MC 68000 series microprocessors were substituted and eventually a different reduce-instruction-set was implemented. These various steps gradually raised the control "core" of the system to reach five times the original capacity. All but the first improvement are known as "Super-core", and Supercore is part of a larger system improvement known as "SuperNode" [27]. With Supercore, the DMS100 system capacity went from 36K to 60K Centrex lines. The Supercore control operates at 20 MHz, but internally some elements may go as high as 50 MHz. Ultimately the Supercore control is expected to be in the 650,000 to 1.5M BHCA range.

SuperNode includes not only the improvements in control capacity, but also a general improvement in the central portion of the system, with a new bus system. These buses provide access to a number of central functions such as the control core, the common channel signaling links, STPs, SCP data bases (see Chapter X-6), and other applications such as digital access cross-connects (see Chapter VIII-7) and packet switches.

The first SuperNode was cut over in Rockingham, North Carolina, on May 12, 1987, as a 10,000 line office. Just as occurred when AT&T upgraded its No. 1 ESS with the 1A Processor (see Chapter V-1), the SuperNode was very popular with over 800 installations scheduled soon after the first successful cutover. It was applied to all versions of the DMS100 family, including the SL100 PBX. The first DMS SuperNode with signal transfer point capability was cut over in Chattenooga, Tennessee, early in 1987.

One objective of the US$ 50 million SuperNode development was to benefit the telephone companies by making it easier for them to do their own Custom Programming. Most of the major central office system developers in the United States are attempting to find a key to reducing development time and expenses by permitting the telephone companies to modify or link various software modules according to their own needs without assistance from the manufacturer-owners of the software. At the time of writing, there had not yet been any notable achievements or experiences in this important area of system deployment.

11. A conclusion

In summary, Northern Electric's entry into its Digital World is an historic demonstration of market penetration. Some attribute much of the firm's success to divestiture of the BOCs from AT&T. However, there is no doubt that early recognition of the direction technology would take, and the determination and resolve by the leaders at Bell Northern Research, were major factors in these accomplishments. This is one of the best examples in switching of being at the right place, at the right time, with the right products.

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CHAPTER VIII-9

THE L.M. ERICSSON AXE DIGITAL SYSTEM [1]

1. Evolution or new system?

The history of the AXE system of L.M. Ericsson and Ellemtel [1] gives us a chance to peer into the future. It was the first system to enter and survive the evolutionary process. It has evolved successfully from a space-division switch, described in Chapter V-10, to the digital time-division switch described here. Evolution, rather than a complete new design, is the path that many switch developers and manufacturers have chosen to embark upon for the present (1989), until new technologies, possible radical new requirements and factors of competition make it necessary to justify once again the expenditure of over one billion U.S dollars to develop a switching system of a new generation for future networks and central offices.

Even the designers of the AXE switch were faced with the dilemma: developing the AKE13 space-division switch for local exchange applications or starting a new switch design. Perhaps it was fortunate that they had had their fill of troubles with the AKE13! This seemed to dictate a new switch development which would be more costly, at that time perhaps as much as $50,00,000 more [2]. However, a completely new switch had the disadvantage in the highly competitive markets of Ericsson of taking longer to develop. At that time, early 1972, the estimate was five years with available effort [3]. The final decision, which proved right, was for a new design.

2. Avoiding multiprocessing

The earlier problems with the AKE system also influenced the control philosophy for the new system. Some of the difficulties with the AKE system could be traced to applying SPC to multiprocessing. While many later system proponents claim to have this capability, being the first to adopt this technique to real-time systems entailed advances in the art that required additional development time.

Regarding with insight the success of the hierarchical method for obtaining greater capacity in the No. 1 and 4 ESS systems with signal processors (see Chapters V-1 and VIII-6), it was quite natural that the design team lead by Björn

[1] Ellemtel is a joint stock company in which LM Ericsson and Televerket (the Swedish telecommunication Administration) hold equal shares (see Chapter V-10, section 7).

[2] Imagine the change. If one ignores for the moment the requirements for different markets, this represents a 20 fold increase in the cost of developing a new system in just 15 years from 1972 to about 1987, a rate of about 22% per year. Even before entering the United States market, by 1982 Ericsson had spent more than US$500 million on the development of the AXE system.

[3] Actually, the first digital exchange at Södertålje, Sweden, was cut over in March 1977, exactly in the forecast delay [2].

Svedberg [4] should use the hierarchical "regional processor" concept. This concept not only relieved the central processor of more frequent and routine functions but also allowed the central control to play a more important role in call processing. This philosophy continues at LME where ever more powerful central processors are being developed and deployed for the AXE system [3] (see section 5).

3. Taking advantage of "regional" modularity

The success in the evolution of the AXE system is in no small measure a tribute to its architecture. The AXE architecture was the result of studies made at Ellemtel shortly after it was formed in June 1970 (see Chapter V-10, section 8). The essential term was "modular": modularity in design but also modularity for installation and modularity for maintenance.

A functional analysis of processing power requirements for each function in a telephone exchange had resulted in the sort of curve shown in Fig. 1. This analysis determined the two-level structure of AXE's data processing system:

- one central processing system, CPS, handling the complex tasks;
- the simple, repetitive tasks delegated to a pre-processing level, the so-called "regional processing" system, RPS.

An important part of the modular concept choice of the early 1970s had been the decision to use "switching logic in memory", i.e. SLIM [5], rather than logic circuits. This meant that each module had its own small stored program capability, with data belonging to a module not accessible from another module. About this time microprocessors were just coming onto the market and this was an ideal application for them. The periphery was divided into units, or modules, for functions that require more frequent, simple and

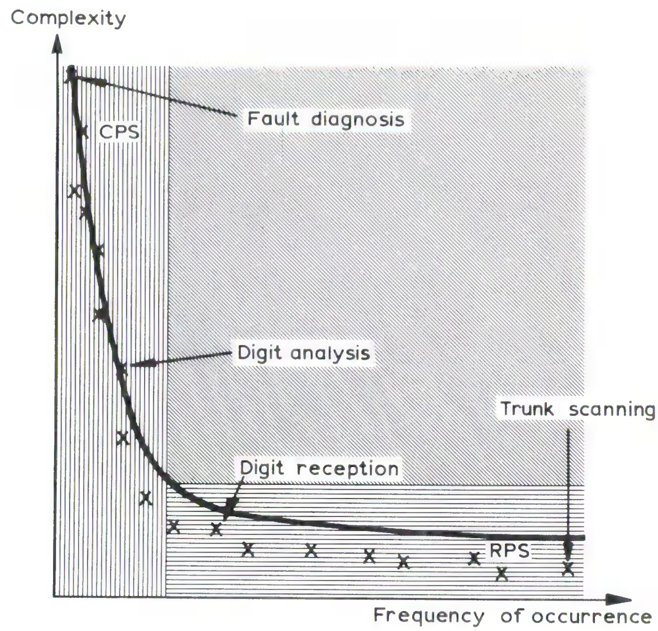

Fig. 1. Relation between complexity and frequency of occurence for different types of functions.
- The frequency of occurence illustrates how often a function is performed.
- The complexity corresponds to the logical power to perform a function.

CPS = Central Processing System
RPS = Regional Processing System

highly repetitive tasks. The control of these modules was assigned to small processors. These were called "regional processors", perhaps somewhat misleadingly since they had nothing to do with geography. This architecture made it relatively easy to add or change blocks in the system.

As with the central processors [4] (see section 5), the regional processors have been improved as microprocessor technology has progressed. The digital AXE system has taken advantage of this and, using more powerful microprocessors, has gradually increased the functions performed in the peripherals.

4. Origins of digital switching in the AXE system

4.1. The evolution to digital switching took direct advantage of this architecture. Similar to all

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4) Later to become president of L.M. Ericsson.

5) Quite early in the invention of stored program control the writer (AEJ) used this same acronym to "promote" the SPC concept.

early digital time-division switches, the design architecture of the switch started from the central switching network, called the "group selector", and worked outwardly.

The initial AXE technology had used space-division with reed switches for both the "subscriber subsystem" and the "group selector subsystem". Not too long after this space-division design was initiated, the designers realized that, should the cost of digital memory and integrated circuits be reduced as expected, they could change the central switch from space-division with reed switch technology to digital time-division with a T-S-T architecture and integrated circuit technology.

This effort was started in 1975 in Ericsson's Australian laboratories [6)], with a laboratory model demonstrated at the end of the same year. The first cutover of the time-division version of the central switch took place in late 1976 and the first exchanges with digital group selectors, known as the "group selector subsystem (GSS)", were placed in service in Saudi Arabia in December 1978. (In Saudi Arabia transportable exchanges were popular installations.) Earlier in 1978, another exchange with digital group selectors was placed in service in Naples, Italy.

Althought Ellemtel worked closely with the Swedish Administration, the first exchange with digital GSS in Sweden was not placed in service until 1980. Table 1, from [3], shows the introduction times in Sweden of the various digital types of AXE system.

4.2. As with most successful time-division systems, trunk-to-trunk tandem switching came first. The AXE system had the advantage that it could continue to be offered as a local exchange using space-division line concentrator stages with their regional processor and digital group selectors. The system later grew with digital line stages when they became available.

[6)] Some claim that there was internal design competition between the Australian house, L.M.Ericsson Pty Ltd., and FATME, the Italian house, where similar digital group selector design was going forward.

Table 1

System	Introduced in Sweden in
AXE telephone switching:	
Digital group switching	1980
Fully digital	1984
Rural version (500–10,000)	1985
Remote digital concentrator (30–2000)	1984
Mobile telephone switching	1981
Various digital PABX systems	1979
AXB, data switching	1980
AXB, telex switching	1977

Between 1978 and 1982 all the exchanges delivered contained only digital group selectors [7)]. During this period the analog-to-digital conversion was achieved by using digital line multiplex terminals in the reverse direction in the line-trunk group junctors.

The first exchange to have both digital group selectors (GSS) and digital line units, called "Subscriber Selector Subsystems" (SSS), was cut over in Tammerfors, Finland, on May 26, 1982.

5. New central processors for AXE 10 [4,5]

Different versions of the central processing system, "APZ", were successively developed to increase their processing power and the traffic capacity of an exchange. These developments were parallel to the expansion of the time-division switching network of the group selector subsystem.

For exchanges requiring a traffic capacity of up to 150,000 BHCAs, two types of processors were available:

- the APZ 210, the standard processor until 1983,
- the APZ 211, a modernized version of APZ 210 with improved characteristics such as smaller physical size, which became the standard version for medium size exchanges.

[7)] However, those delivered in France (see Box A) during this period did not include digital group selectors and were with a space-division switching network.

Box A

Ups and downs of LM Ericsson systems in France

The French subsidiary of the LM Ericsson Company, the Société des Téléphones Ericsson (later to become the "Société française des téléphones Ericsson" – SFTE), was founded in 1911 after an international tender to provide the French Administration with large manual urban exchanges (8a).

Act 1: 1924 and 1926. – One of the first exchanges, a prototype exchange, to use the first automatic system of LM Ericsson – the 500-point system – was installed in Dieppe in 1924 [8 b]. It remained in operation until it was damaged beyond repair in the Second World War.

In 1926, this LM Ericsson system found itself competing with the Siemens HDW (step-by-step) system and ITT's Rotary system for the automation of the Paris network. ITT won the contract [8 c] and SFTE was to spend many years on the fringes of France's public switching market, only as a modest sub-contractor producing the ITT Rotary system.

Act 2: 1960. – When the French Administration eventually decided in 1960 to adopt crossbar technology for its automatic exchanges, SFTE succeeded in placing its CP 4OO, a French version of LM Ericsson's ARF crossbar system [8 d]. For the next decade and a half, exchanges of this type were to become the standard equipment of many French towns outside the Paris region.

Act 3: 1976. – This year was characterized in France (see Box A, Chapter V-9) by:

- for a large-scale introduction of electronic exchanges in its network, the launching by the French Administration of a call for tenders from the national manufacturers for electronic space-division switching systems. Foreign-designed systems already proved outside France were to be considered, provided they could be manufactured under license by French companies;
- decisions by the Government to require the subsidiaries of foreign multinational groups, with which the orders for such exchanges were to be placed, to be taken over by French companies.

One of the most important of the ensuing events was the French Administration's decision to choose not only the ITT Metaconta system but also the Ericsson AXE system, both space-division versions which at the time had hardly proved themselves at all. As to LM Ericsson's French subsidiary, SFTE, it was taken over by the French Thomson-CSF Group which was then to construct and install French AXE exchanges under LME license.

In four years, nearly one million AXE lines were installed in the French network, mainly in the provinces (the first one installed in Orléans in 1979). According to LME license, export was limited to a few countries of French-speaking Africa. In the mid-1980s the orders placed by the Administration with Thomson-CSF-Téléphones became no longer for AXE exchanges but for exchanges of the MT system (in service in 1982–1983). The earlier AXE exchanges were space-division and manufactured under foreign licence, whereas the MTs were digital and of French design. Once again then, systems of LM Ericsson design were to disappear for a while from the French scene.

Act 4: 1987. – One of the ITT Group's two French subsidiaries, CGCT, had escaped the process of Frenchification imposed during the 1976 restructuring of the switching industry. But not for long: in 1982 CGCT not only had to become a French company but in addition was nationalized [8)] by the new socialist Government. Stripped of its links with its former parent company and with hardly any research and development facilities of its own, the company – now a public corporation – steadily went into decline. To keep CGCT's head above water and afford its staff a living, the Government took it upon itself to grant the company a fixed 16% of the Administration's order book. When even this proved inadequate, it decided in 1987 to open up some of the company's stock to a foreign partner who was to be allowed to take a correlative share of the French market for its own switching system.

The stakes in this new form of competition were certainly not vast, amounting as they did to the famous guaranteed 16%, i.e., 200.000 – 300.000 subscriber lines per year, but there was the prestige of the selection by France Télécom.

Box A (continued)

Once again there was fierce competition. The main battle was between two giants, namely ATT/Philips (APT) with its European version of the ESS No. 5 system and Siemens with its EWSD system. In the early stages the ESS No. 5 was clearly in the lead. Then there was a change of government and considerations of European policy gave the edge to Siemens. After much shillyshallying, it became imperative for the French Government to make up its mind and take a decision.

It is hard to know whether the winning system was chosen exclusively on its merits or whether the idea was to avoid causing either of the two most ardent pretenders to lose diplomatic face. The choice eventually went to the AXE digital time-division system, to be produced by a joint venture of LM Ericsson and the MATRA French company.

Once again, LM Ericsson systems re-emerged, – as it were, resuscitated –, on the French scene.

8) In other words it was taken over by the State and ITT was compensated.

A third type of central processor, APZ 212, the "AXE supercomputer", was developed between 1980 and 1983. Under the direction of Oleg Avsan, a team of over 300 specialists in CPU design, microcoding, operating systems, compilers CAD, component technology, printed circuit boards and manufacturing methods designed this new processor, a project which was considered as one of the most creative development work in the Ericsson group.

The APZ 212 provides a traffic handling capacity of 800,000 BHCAs and increased by a factor of six the call handling capacity of AXE exchanges. Such a capacity made AXE 10 equipped with APZ 212 very suitable:

- for large national or international transit exchanges,
- for local/tandem exchanges in metropolitan centres, characterized by high traffic per subscriber,
- to implement and cope with any ISDN functions.

AXE 10 exchanges are equipped with two redundant central processors. The two APZ 212 of an AXE exchange operate in dual micro-synchronized mode.

The design of APZ 212 utilized new technologies both at component and circuit-board levels. Semi-custom gate arrays in an in-house pattern design enabled component packing densities to be increased considerably. A special technique was used for circuit-boards, built up from 17 individual layers, pressed and bonded together under high pressure. All these arrangemnts provided a very compact APZ 212, its physical size having been reduced by a factor of six compared with the initial APZ 210 processor [6].

6. The presence of LM Ericsson systems in France: on again – off again [7]

The history of the LM Ericsson systems in France is a long one. It is also complicated, with a series of ups and downs, and anyone wishing to know all its intricacies, is referred to Box A.

More briefly than in Box A, it can be said that a completely analog version of the AXE system, with a 2-wire space-division switching network, was produced in France from 1979 (Orléans exchange) to 1984. By 1984 when this production ceased, there were nearly one million lines of this AXE analog version in service.

In 1987, at the issue of an international tender, the French Administration decided to turn again to the digital AXE for a 16% share of its orders, to be produced under a joint venture between Ericsson and Matra, a French company [9]. Matra/Ericsson (MET) handed over the first French time-division AXE exchange in February 1989 (Chaville exchange in the near-by Paris area, 4000 lines host with 16,000 remote lines in Vaucresson). The system included the latest high capacity central control, the APZ 212 with two

32 bits processors. Orders were then placed for 150,000 lines with the next office scheduled for Cévennes/Michelet (Paris network) in December 1989, after commissioning of the Chaville pilot exchange.

7. Coming to the rescue elsewhere – Switzerland and the U.K.

The return to France in 1987 is only one of several examples of where, over a long period and with an appropriately modern system in the AXE, *Ericsson's marketing patience, persistance, and fortunate good position* has paid off. Two other typical examples are Switzerland and the United Kingdom.

7.1. After the Swiss PTT decided in 1983 to cancel the development of their ambitious "integrated telecommunications system" (IFS) (see Box B) the three Swiss manufacturers of public switching systems (Hasler Ltd., Albis-Siemens AG, and Standard Telephon und Radio AG (STR)) were asked to offer systems with the cooperation of successful system manufacturers from around the world. Albis-Siemens offered the EWSD system; STR, then an ITT affiliate, the System 12 (1240). Hasler, in Bern, was the only Swiss manufacturer without an international affiliation. In 1984, it decided to enter a license agreement with L.M. Ericsson to adapt the AXE 10 system to meet Swiss PTT requirements and to gradually produce it in its Bern factory [10]. The first local AXE exchange for Lucerne was delivered in June 1987. Several later installations for Swiss cities included a Centrex exchange for Basle and an ISDN exchange in a container for Biel.

7.2. In the United Kingdom the situation was different. As indicated in Chapter IX-5, System X was developed in this country under the sponsorship of the British Post Office, then succeeded by British Telecom (BT). While System X deployment was adequate for the toll network, local system deployment lagged. In the new competitive environment in which BT found itself, it was necessary to consider further manufacturing resources.

In 1985 BT solicited proposals from manufacturers wishing to produce public exchanges in the UK. Years before, Ericsson Telephones in the UK had been bought by Thorn. It was quite

Box B

Switzerland – Its system IFS: what happened to it?

What the Swiss PTT was really looking for when digital telecommunications appeared on the scene in the early 1970s was later to become known as ISDN. The specific Swiss system they had in view in the 1970s was called the "Integrated Digital Communications System", which in German becomes IFS (F = Fernmelde) [11]. The intention was to develop for Switzerland a complete set of nationwide transmission and switching systems to provide both telephone and data (telex) services. The emphasis was on high availability and reliability. Some elements of the network were to be triplicated. All three Swiss manufacturers cooperated with the Swiss PTT in this project.

Planning and development on the IFS proceeded for more than 15 years. A laboratory model of major system elements was built and the switching system was being prepared for a field trial. In the meantime the telex network had been modernized with the development and deployment of the Hasler SPC "T200 Telex and Data Exchange" system, starting in 1978.

The Swiss administration finally decided that the state of the art had caught up with their objectives and that satisfactory products were now available from the world's equipment suppliers. Furthermore the reliability aspects of the network plan made it uneconomical [12]. In 1986 they invited proposals from the national manufacturers for the digital telephone switching portion of the network. The new digital Swiss network is known as SWISSNET [13].

natural then for L.M. Ericsson to join up with Thorn. They became the successful bidding team with the AXE 10 system. For its applications in the UK, the AXE 10 was sometimes renamed System "Y".

For LM Ericsson, after an effort of over 17 years trying to break into the UK market, this represented an eventual success. The first order was placed in August 1985 for 500,000 lines in 50 exchanges. The first exchange, at Sevenoaks, was handed over in September 1986 but not commissioned until somewhat later. Larger orders were placed later and included Centrex service. The AXE 10 system in the UK was the first time-division digital switching system outside the United States to provide Centrex service.

Before the decision of British Telecom to choose the AXE 10 for deployment of local exchanges in its network, its international branch, British Telecom International (BTI), had already chosen the AXE 10 to equip its seventh international gateway [9] in London, the one at Keybridge House. Also supplied by Thorn Ericsson and handed over in early 1984, it was the world's largest digital transit exchange of its time (53,000 long distance circuits in 1985, with a 800,000 BHCA capacity offered by the then new Ericsson APZ 212 processor).

The Ericsson-Thorn joint venture also supplied offices to the Racal cellular mobile service network.

8. Success throughout the world

8.1. By the end of 1988, 28 million lines of the AXE 10 system were in service or on order in 75 countries. Almost 1800 exchanges serving 19 million lines were in service. From 1985 to 1989 the successes in France, Switzerland and the UK almost doubled Ericsson's share of the European market. The largest sales have been in Sweden, Australia, Korea, Italy, UK, France, Netherlands, Malaysia, Spain, Brazil, Columbia, Tunisia, Morocco, United Arab Emirates, China (P.R.), etc.

It is noteworthy that Ericsson with its AXE system has had many world successes when administrations (or other manufacturers) for a variety of circumstances required the presence of another manufacturer. This was true in Norway and Mexico when ITT had problems with its 1240 system, in France and England as accounted for above, and in Switzerland with the demise of the IFS-1.

8.2. It took a while for Ericsson to develop remote switching units (RSUs) for the AXE system. The first was placed in service in 1984. However, many of their potential markets, e.g. Norway and Australia, could use small rural and transportable exchanges to advantage. In Australia, such a system, designated as the AXE 104, was developed with potential sales of 3000 echanges. The AXE 104 has a maximum capacity of 2048 lines and a 10,800 BHCA capacity supplied by a smaller processor, the APZ 213. It has no group switching subsystem.

8.3. From very early in the electronic switching era (1960s) it was realized that centralization of maintenance and administration would be not only economically attainable but of great advantage in offering improved response to service needs. A follow-on development associated with the AXE system was a unified "Administration, Operation and Maintenance system", the AOM System 101, that has been sold in 27 countries. (Even if the AOM 101 system can be used with a diversity of exchange systems, the presence of an AOM 101 network in a country was sometimes a non-negligible advantage for further selection of AXE exchanges in that country.)

8.4. The AXE switch has also been exported to East European countries. First to Hungary, to be used for training and evaluation by Electroimpex for International Gateway in Budapest (this was one of the first SPC system to be exported to these countries since COCOM relaxed its rules). In 1989, renewing the presence of LM Ericsson in Russia after 70 years (!), the USSR Adminis-

[9] The UK's international traffic was currently doubling every five years.

tration also ordered AXE exchanges, the first ones for installation in Leningrad.

9. Success in mobile switching

While cellular mobile radio (800 MHz) was first researched and explored by AT&T Bell Laboratories in the United States, the regulatory process delayed its commercial introduction until 1983. In the meantime the Nordic network [14] (900 MHz) was developed using a version of the AXE 10 switch and deployed in Sweden, Denmark, Finland and Norway [15]. It quickly became and (in 1989) remains the largest mobile network in the world.

After its introduction in the Nordic Network, the AXE switch was well received elsewhere for use in the cellular radio telephone service and 38 such offices were put into service in the United States and Canada.

By the end of 1988, more than 160 AXE offices had been installed or were on order for use in mobile services and were serving about 40% of this world market. The system capacity has been upgraded to 200,000 BHCAs by using the APZ 212 processor to replace the APZ 210. This was first accomplished in the United States in Chicago, Illinois. in January 1987.

10. Cracking the United States market

Many manufacturers have failed to succeed in the United States generally due to the high costs associated with the continuing stream of unique developments required for the market there. With the American use of the AXE system in the cellular mobile radio switching field and then a foothold in America, Ericsson decided in 1985 to expand its presence with the objective of selling local and tandem exchanges to the Bell Operating Companies (RBOCs). LME recognized that establishing this presence in the US market would be costly and take time. They pointed to the 17 years they had had to wait in the UK. Ericsson was willing to spend some US$150 million to adapt the AXE system for the US market. It turned out that this was nearly the annual cost rather than a one-time cost.

The RBOC market had been held primarily by Northern Telecom with its DMS products and AT&T Network Systems with their No. 5 ESS. Ericsson's approach, as with most seeking to enter a highly competitive market, was to find a niche of its own. They adopted several tactics to interest RBOC companies in buying the AXE system. Three in particular were small offices, signal transfer points (STPs), and "customer Programmability".

Many of the regional RBOCs purchased or negotiated for laboratory models or sample installations of the system. US West and BellSouth ordered systems to be used as STPs. One of these offices was placed in service in Canon City, Colorado, in November 1987. It combined the local office with the STP function, a combination that could have future applications as the RBOCs expand their local signaling networks [10]).

One regional RBOC, NYNEX, became interested in the AXE system because Ericsson had pioneered in allowing customers to use their own software development tools. The long interval – in the order of three years – needed to deploy new system services and features once agreement has been reached on their requirements, has been an issue in the deregulated United States market. Allowing telephone companies to be responsible for their own programming is thought by many to be an opportunity for improving the situation. Most developers and manufacturers are now addressing this issue.

By the end of 1988, 108,000 AXE lines in 23 offices were in service in the United States. Several large orders are awaiting results of trials of these systems.

The AXE system has also been sold in the United States to one of the independent interex-

[10]) It should be noted that the AXE system as deployed in the Swedish network was equipped with signaling system No. 7 (see Chapter X-5). The STP function is included in local exchanges. The CCS No. 7 signaling network was introduced in Göteborg in February 1985 and, by the end of 1987, included 85 exchanges.

change companies, MCI. They have used it for international gateways with signaling system No. 7 and have purchased the AOM 101 system as well.

The United States market is one where Ericsson has used its development skills to foster its international markets for the AXE switch. Here the non-US manufacturers learn about services such as Centrex, Broadband-ISDN, Intelligent Networks including "rapid service introduction", open system interfaces, private networks, etc., all of which are planned for the continuing evolution of the AXE system, for marketing throughout the world.

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Part IX

A second generation of digital systems (post-1980 systems)

CHAPTER IX-I

INTRODUCTION TO PART IX
WHY TWO GENERATIONS OF DIGITAL SWITCHES?

1. A view of the first generation of digital swiching systems

Time-division digital switching started some 10 years after the initial installation and use of time-division multiplex transmission. It started slowly: sufficient digital trunks had first to be terminated on space-division switches before consideration would be given to their interconnection through the switch without conversion to analog transmission.

Switching systems with space-division concentration and in some cases less than fully stored program control were in retrospect the first generation of time-division digital switches. Most of these systems have been covered in Part VIII.

For the most part, the organization or architecture of these early, first generation, time-division digital switches evolved from the space-division era. The switching networks had conventional concentration and distribution stages located in the central office. The control portions of the systems were highly centralized with some – and only some - hierarchical control in independent signal processors or in simple microprocessor controls associated with the concentrator stages.

The cost of digital technology decreased as predicted. As this technology improved, there was the extension of the application of electronic time-division digital switches with full stored program control to local offices (see Chapter VIII-2). This was important for two reasons. In many cases, e.g. the smaller United States independent telephone companies, for the first time the advantages of stored program control were reaching to the subscriber line terminations. At the same time the systems brought digital connectivity ever closer to subscriber premises. The potential for the realization of IDN (Integrated Digital Network) and ISDN (Integrated Services Digital Network) greatly increased.

2. A general comment on the evolution of switching systems

In the development of switching systems, it has been characteristic that, after a new technology first appears, there is usually sufficient justification to improve or revise the initial designs to take advantages of feedback from both Operating agencies (the users) and the designers [1].

Usually the design of a system progresses to a point where it is no longer possible to make desirable changes to keep pace with the technology without unduly delaying the introduction of the product. If the initial development proves in the marketplace to have sufficient advantages to justify its adoption, changes and improvements are made in a later redesign. It is then that the true merit of one architecture over another is realized by both the designers and their customers

[1] see footnote on reverse

3. Distinguishing between first and second generations of digital switching systems

By the early 1980s, sufficient experience had been gained with time-division digital switches and many manufacturers of new switches justified the development of new systems with a different emphasis in their architecture and organization. This Part IX describes these newer systems, (the post-1980 systems), and the changes that resulted from their introduction.

As this emphasis on different system organizations became understood and accepted, many of the systems introduced earlier were revised or amended to provide similar functions or equivalent capabilities.

For time-division digital switching there was a great difference in introducing a new generation switch over previous experiences in the industry. In general there was a spontaneous move forward with this new generation, rather than a single new system design leading the way. The reason for this was that the digital technology that sparked off the first generation came from outside the industry, a fact that some of the manufacturers promoted with appellatives like "Digital World" and "Digital Century". At that time (early 1970s to early 1980s), there was no technology being used that was unique to switching.

It is difficult to compare the history of systems when the more recent of them are catching up in the development of their software, or are only just starting to come into general service, or to know when those others which have reached maturity are still undergoing substantial modifications.

Most objective experts know a new generation switch design when they see one. In the case of time-division digital switches there has been an acceleration of the process of recognizing a new switch generation. There has been a "push" by the rapid changes in the cost and capability of the digital technology. There was also a "pull" initiated by the large growth of new services and the software to implement them.

Chapter IX-2 describes in detail some of the more significant parameters that distinguish our two generations of digital switching systems. The most important are the "distributed" and "remote" capabilities that were included initially in most second generation switches.

4. A Caveat

The reader is requested to excuse any irrelevancies or omissions by which, in Part IX, the following account might be flawed. Please try to refrain from shooting the pianists! Despite the wealth of recent publications, articles in the Press and often startling publicity which has occasionally been belied by events, the authors sometimes had great difficulty in discovering what score is supposed to have been played over the past five or six years in the telephone switching industry.

To what extent does an intendedly historical account tend quite naturally to become a mere journalistic report on facts which have been daily altering the course of events, especially when

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[1] Throughout the history of switching many examples are found where significant improvements were made in existing systems resulting in new generations of the same system:
- the No. 1 manual switchboard (1897) of Western Electric was replaced by the No. 1C (1909) with many added features [1],
- the initial HDW system of Siemens was replaced in 1925 and 1927 by models with smaller switches [2 a],
- the "panel" switching system with battery (1927) replaced the one with ground on the cut-off relays (1921) [3 a],
- the McBerty (1906) system was replaced by the post-1920 Rotary systems No. 7 of ITT [2 b],
- the No. 5 crossbar system with flat spring relays (1948) was replaced by the one with wire-spring relays and smaller crossbar switches (1953) [3 b],
- the No. 1 ESS (1965) was replaced by the No. 1A ESS (1976) with improved reed crosspoints and central control [3 c],
- etc.

While most modifications to the step-by-step system were evolutionary, the British Post Office did succeed in introducing a complete new generation with the 2000 type switch [2 c].

Generally introducing large and costly redesigns is the luxury of the more prominent manufacturers.

such facts include spectacular decisions to start – or to stop – introducing a system in this or that country or continent, or the merging of manufacturing companies? Moreover, never has the history of telephone switching been so crammed with events of this sort than in the years covered by this Part IX, so much so that there is a real danger of the forest being hidden by the trees.

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CHAPTER IX-2

EXTENDING TIME-DIVISION SWITCHING

1. Introduction

In addition to the architectural differences of the second generation time-division digital switches and their derivatives, new services and applications of switching systems have been engendered. At the time of writing this era has only just begun and it is too early to record all that may evolve from it. Some of the more important possibilities are examined in the following three sections.

2. Distinguishing distributed control and distributed switching

It is sometimes difficult to attribute to specific changes the demarcation of a new generation of design. It is a subjective matter. The widespread use of the word "distributed" is a characteristic that has been selected by the authors to direct attention to the major new attributes that have been introduced into time-division digital telecommunications to justify the designation of a new generation of switches.

Defining "distributed" as applied to telecommunications, and in particular to switching centers, is also difficult. In the broad sense specifically and from the layperson's point of view, a network of switching nodes is distributed geographically over the landscape, to attain the best balance between transmission and switching costs at any one time period. New inventions shift the economics as occurred when fiber optic transmission was introduced and further reduced the cost of broadband transmission.

The change in the geographically distribution of switching entities has come more gradually, pushed by the use of new technologies, the most important of which were the VLSI semi-conductor devices and the general use of microprocessors. While, physically, smaller distributed switching systems result from the use of smaller components, the more important factor is the intelligence that can now be built economically into a small switching entity.

"Distributed" in the context of this chapter more frequently applies to the architecture of a switching system entity itself. Equipment "modules" are designed to serve groups of system terminations, be they lines, trunks, data links, etc. Applying the latest VLSI technology to these modules results in their controls becoming somewhat autonomous. They are completely autonomous if they can complete calls within their modules, or directly with certain other modules completely independent of controls elsewhere in the system.

2.1. *Distributed control*

This distributing of the call and information processing requirements of the system has given rise to this generation of "distributed control" SPC switching systems. The call processing in these systems may be shared by the controls in different modules and, if it is provided, a central control. The latter is omitted in systems that

have claimed to be fully distributed [1]. The balance of call processing among the modules and the central control is a matter of design judgment. Generally, the more call processing placed in the periphery, the greater the total call capacity of the system.

The number of terminations served by a module can vary widely with the system architecture. In some systems the module is several hundred lines and, in others, thousands of lines. This also relates to the power of the microprocessor chosen as the control element.

2.2. *Distributed switching*

Distributing the control is but one aspect of second generation time-division digital switches. Another use of the term "distributed", sometimes related to distributed control, is to include "switching network" capability within the module. In some systems, calls between terminations on the same module can be completed without passing through any of the other system elements. This is known as "distributed switching". The extent that a design includes this attribute varies considerably among system designs.

In some systems the distributed switching provided in the modules is used only to connect signaling elements to the module terminations. The modules of other systems provide complete message paths for connections that may be completed within the module.

Both distributed control and distributed switches are the criteria that define our "second generation switches". The switching systems described in this Part IX are believed to have met these criteria in their initial design.

[1] Fully distributed control and switching has been compared with the first successful and enduring switching system, the step-by-step system, whose history was thoroughly covered in Volume I, Part V. In some respect the 1240 system (Chapter IX-7) attempted to be an electronic step-by-step system. It remains for the reader to decide if the use of some of its modules, such as the Auxiliary Control Elements (ACEs), not used for the circuit switching of calls, is a divided central control or a distributed control.

Some of the switches described in Part VIII have since the early 1980s been modified so that they may now be considered members of the second generation "club". The functionality of some of these systems has also been changed, so that they might now be considered second generation switches.

For new and revised systems many other improvements have been made to increase their traffic capacity, and their programs have been expanded to provide for more services. A general pattern is emerging. Specific module designs are used to introduce new services. This follows the history of switching system evolution with respect to services and features. They are first introduced in the periphery and, if successful, are included in the core of later system generations.

3. **Remote switching**

3.1. Cost and capacity considerations are a major factor in locating switching nodes relative to transmission facilities. The switching modules of the new generation of time-division digital switching systems may be located outside of the local central office. The central offices are called the "hosts" and the modules, called "remote" modules. With the availability of remote switching modules that are not only small in size but high in capacity, it is now possible to provide a new geographic prospective to telecommunication networks [2].

New signaling capabilities have also played a role in extending the range and manner by which switching nodes communicate with one another. The extensive use of common channel signaling in the future portends even more in changes in the distribution of switching intelligence in telecommunication networks. It is not the purpose here to prognosticate about the future of tele-

[2] Many attempts were made in the past to "decentralize" or "distribute" switching. For example, as early as 1904 it was proposed to locate step-by-step switches in the basements of apartment buildings to save cable pairs to the central office.

communications but to indicate the impact the second generation switches are already having in their application.

With electromechanical switching, many attempts were already made to bring switching closer to the subscribers and thus to reduce the cost of outside distribution or feed cable plant. "Remote line concentrators" (RLCs) using space-division technology were developed and deployed, but with limited success [3]. Operating units outside of a central office in an environment that is relatively hostile, and high maintenance costs associated with the use of this technology were among the reasons for their lack of success.

With semiconductor technology, a new era opened up, not only to switching but also to transmission. It was now possible to employ reliable active devices in the feeder and distribution cable plant. As a result the transmission designers brought forth "subscriber line carrier" (SLC) systems. These systems were called by some "pair-gain" systems, since they could serve lines over fewer cable pairs. Early SLC systems employed frequency multiplexing for analog transmission. Later, starting in 1971 in the United States, PCM systems were deployed and these have been very successful (see Chapter VIII-2, section 5) [1].

With SLCs, each line is served by a channel and has an appearance at the central office. While SLCs usually serve less than 100 lines, in some applications multiple SLCs have replaced small central offices. Also some SLCs have included a simple switching stage of concentration, usually with a ratio 2 : 1.

Attempts at electronically controlling space-division RLCs also met with little success [2]. Not only was maintenance expensive when required, but so were the monitoring circuits required to test for troubles at the remote location.

3.2. With the advent of microprocessors and lower cost electronic crosspoints, other attempts at remote switching were made [3]. While some industry writers use the terms loosely, the differences between "remote switching" and "remote concentration" should be noted. In the latter, all calls originating and terminating at the remote unit must pass over trunks to the central or "host" office to which they are connected. This means two trunks for intra-concentrator calls. Where there is high intra-unit calling, the grade of service can become rather poor.

For Remote Switch Units ("RSUs") provision can be made for an important attribute, viz. serving intra-unit calls at times when the trunks to the host are all temporarily disabled, for example by a cut cable. Since the first of the RSUs were developed, a wide variation in their capabilities have been implemented by different manufacturers. Generally the intra-unit calling capability has been called "stand-alone". For large RSUs this feature is sometimes used only for emergencies since the control at the remote unit does not contain a full complement of call processing programs providing all of the services (e.g. coin service), normally available when the RSU is connected to the host.

With second generation systems, RSUs have increased in capacity, sometime serving as many as five thousand lines. All RSUs interface efficiently with digital trunk carrier systems. Their range has been extended by the use of fiber optic links to carry the trunks to the host, one hundred miles or more in some cases. The application of these units in the United States has been to reduce the number of wire-centers, particularly those serving smaller communities.

Newer provisions have been to colocate several RSUs and to provide trunking between them. This has been called "clustering". Some RSUs use the same system and modular architectural design as the manufacturer's host system. As the need grows for more capacity, RSUs may be upgraded to complete host offices. RSUs may also act as "hosts" for SLCs and RLCs.

3.3. The software control of remote switches varies widely among systems. While organizations such as Bell Communications Research (Bellcore) attempt to set standards for the inter-

[3] The success of the first local digital switch, the E10, was partially dependent upon employing this type of remote line concentrators.

change of information between remote and host switches, competitive pressures are unlikely to yield. The control of one manufacturer's remote by another's host has not occurred at the time of this writing, except the few cases where the host's manufacturer has permitted it (see Chapter VIII-10).

4. ISDN in prospective

The modular design of second generation switches has facilitated the modification of system designs to provide for Integrated Services Digital Networking (ISDN). For many of these system designs, ISDN modules started with proprietary designs specific to the pre-standard ISDN interfaces. As standards became defined and accepted, these ISDN modules were modified, or new ones with the standard interfaces were provided.

New modules to accept ISDN digital subscriber lines have been designed. These modules include call signaling processing and, in some cases, means for receiving and passing along packetized data messages.

All systems providing ISDN services also include in their basic capability provision for common channel signaling system No. 7. This is an absolute need to extend in circuit-switching the ISDN messages to distant offices. As a result, ISDN can be extended to customers no matter where they require ISDN service. Some designs include ISDN provision for CENTREX customers, the central office switches serving all of the station switching needs of a business establishment.

Some switch designs have also made provision for replacing line-circuit cards serving a small number of analog lines by digital-line circuit cards serving a smaller number of digital subscriber lines. The following Chapters of Part IX, describing specific second generation systems, give more details on arrangements made for ISDN in these second generation systems.

The technique of providing new modules for adding ISDN, or any other new service, facilitates these service implementations without modifying the entire system. This is a basic characteristic of second generation systems.

Similar plans are now being implemented for present or future features such as the provision for "Signal Transfer Points" (STPs) of signaling system No. 7, optical line interfaces, and broadband ISDN services. (The internal time-division transmission links between sections of the switching network or fabric of many second generation switches are implemented with fiber optics that are inherently broadband.)

5. A new type of PBXs with time-division switching

5.1. The time-division PBXs

This volume is directed primarily towards the history of central office switching. In some cases, central office switches have been used for large PBXs [4]. Also CENTREX service, where stations receive the equivalent of PBX service from a central office that serves the lines of other regular subscribers as well, has grown in popularity, particularly in the North America, since the introduction of SPC local offices.

PBXs have been at the leading edge of innovations in time-division digital switching. The first PBX employing digital switching with SPC was installed in 1974 [5]. The change to digital switching in PBXs preceded the general introduction of this technology in local central offices. One reason for this was the earlier successful application of time-division pulse amplitude multiplexing (PAM) for PBXs [4] [6] (see Chapter II-5, under 3.6).

Many different forms of coding and sampling rates were used in digital time-division PBX switches before the 64 kbit/s rate became the consensus.

PBXs being the basic serving vehicle for commerce and governments are naturally provided

[4] This contrasts to its failure a decade earlier of the more ambitious Highgate-Wood PAM development in the U.K. (see Chapter II-4).

with many unique features. Some of these relate to the access that PBXs have, not only to public networks, but also to private dedicated networks. Many of these features are related to data as well as voice messages.

5.2. *Clustered networks of PBXs*

With SPC switching, clustered networks of PBXs, called "electronic tandem networks" (ETNs), may be formed by establishing connections over private networks formed by the use of trunks between PBXs. Some telephone central offices have also been arranged for the ETN service. Other SPC central office specific designs have been developed or arranged for use in large private networks.

6. Digital data switching [5)]

It is not the purpose of this book to present the history of other than telephone switching. However, as the pervasive and ubiquitous telephone network is converted to digital transmission and switching, it offers the opportunity to be used for digital data as well as digital voice. The challenge is to make the best use of the 64 kbit/s telephone circuit-switched network by variable digital data rates. (The "hype" associated with the introduction of time-division digital telephone switching has often claimed more for the universality – also for data – of the telephone network than may be economically valid!) As indicated below, data rates may vary from a few bits per hour, e.g. for alarms, to hundreds of millions of bits per second for file transfers or for video applications, such as high definition color full motion pictures.

Business uses of telephone networks have been a stimulus to the networking of data terminals and computers. However, the characteristics of data traffic, (e.g. the "bursty" traffic characteristics of access from terminals to mainframe computers), are usually very different from the two-way conversational mode of the telephone.

6.1. *Store and forward message switching*

At another end of the data utilization spectrum, when very large volumes of data have to be transferred from one place to another, one-way data transmissions may continue over a long time period, such as the business day, and take any number of hours. For this application a different form of electronic message switching, "store and forward switching" [7] has developed [6)]. For interfacing with mainframe computers there are "front end" communication processors.

Store and forward message switching systems require large storage capability [9–10]. Generally, entire messages are stored to await the availability of the limited number of network transmission facilities that are provided. Message switching has the advantage that all or part of a message may be retransmitted if not received accurately at the called point. Also each message may be sent to several different addresses.

6.2. *Packet switching*

On the other hand, data messages formed by humans may and, usually, do consist of numerous "bursts" of data only for a few seconds. If a circuit-switched connection is used, the delay to dial a circuit request for each message burst would represent a great waste of user time. The call set-up time is generally longer than the message burst to be transmitted. Packetizing the message bursts with an address on each packet has brought a new form of switching, known as "packet switching" [11–12], and has been largely developed since the 1970s to serve this type of traffic.

[5)] see Chapter XI-2, section 4, on the considerable expansion of data transmission and its specific switching modes since the early-1970s.

[6)] Electromechanical switching using store and forward techniques was a popular method of sending teleprinter messages before the era of electronics switching [8].

6.3. *Packet switching networks*

For the long distance transmission of digital data, the concept of packet switching networks was developed, starting in the 1964 [13]. The first packet switching network, ARPANET, first went into service in the United States in December 1969. For packet switching, data messages are divided into equal length segments that are sent independently over any of a number of links in a network. The segments are reassembled at the terminating switch to reform the complete message. The message transmission in each direction is independent and may be delayed. The initial objective of these networks was to make maximum use of limited long distance transmission facilities.

Since the mid-1970s, international CCITT standards [14] define in great detail:

– in Recommendation X.3, the characteristics of the Packet Assembly/Disassembly ("PAD") device to be used in a public data network [14a];

– in Recommendation X.25, the interface between Data Terminal Equipment ("DTE") and Data Circuit-terminating Equipment ("DCE") operating in the packet-mode in public data networks [14b].

The deployment of packet data networks, especially as public networks, has been an impressive one. It can be followed through the Proceedings of the successive ISSs, since the Paris 1979 ISS, and the articles in specialized reviews reporting on the deeds of these ISSs. As P. Lucas reports after the Florence ISS 1984 in [15], "packet switching is (in 1985) the better solution for networks handling low-speed and medium-speed (non-voice) data... All the industrialized nations have operational or planned public packet-switched data networks. Roughly 50 packet networks are already (in 1985) in service worldwide." The status of packet-switching in ISDN is dealt with in a similar report on the Phoenix ISS 1987 [16].

6.4. *Local area networks*

To avoid tying up PBX connections serving data terminals for too long times, "ring" and "bus" geographically limited networks ("in-house" networks), known as "Local Area Networks" (LANs), employing packet switching and used exclusively for data transmission were proposed in 1959 [17]. The first successful commercial LAN, known as "Ethernet", was brought onto the market by Xerox in 1976 [18]. With the wide use of time-division digital switching in PBXs, there has been some reverse of the trend towards separate in-house networks for data transmission. Furthermore, since PBXs act as gateways to the public network(s), it is often advantageous for many of them to convert external data traffic from digital to analog form by pools of modems in the PBX.

6.5. *Data PBX*

Circuit-switching for data has been developed using lower bit rates, e.g. 9.6 kbit/s and 19.2 kbit/s, rather than the standard 64 kbit/s rate required for voice transmission. PBXs designed for these low bit rate data transmission are known as "data PBXs" [19].

7. Other attributes of second generation switches

7.1. *Improved human-machine interfaces*

A characteristic of the second generation systems is the improvement of the human-machine interface between switches and those persons charged with their operation. For a more user-friendly control, terminals with "menus" on color monitor screens are used instead of teletype coded message and/or extensive lamp and key panels (see Chapter VII-5, section 1.3). These "Operation, Maintenance and Administration" systems are centralized and may serve tens of central office switches, including the remote switching units.

7.2. *Digital signaling*

In-channel ("in-slot") digital signaling and out-of-channel ("out-of-slot") digital signaling

have been used since the introduction of time-division digital transmission:

– out-of-channel was the standard mode within the "European" standards for PCM transmission,

– in-channel was the standard mode within the "American" standards for PCM transmission.

In most second generation systems, to be consistent with the use of signaling system No. 7 (see Chapters X-5 and X-6), out-of-channel digital signaling has become the preferred mode of signaling. Not only is signaling system No. 7 used between central offices and with signal transfer points, but it is also used in some cases between the local host central office and remote switch units.

7.3. The future

Many plans are now on the drawing boards for systems that will provide for future service needs. A history book must confine itself to the past. However for those not wishing "to reinvent the wheel", reflection on the experiences related in this volume should be most useful as they move forward in their quest for the future of switching.

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CHAPTER IX-3

NO. 5 ESS – AT&T'S ENTRY INTO THE TIME DIVISION RACE LATE TO START – LEADING THE PACK

1. Introduction – late out of the starting gate

1.1. In Time-Division Digital Switching, AT & T had set the pace. First with the 1959 demonstration of time-division digital switching in the ESSEX experiment (see Chapter II-4, section 1) including time multiplexing and time slot interchanging, and then with the 1976 development of the first SPC digital time-division switching system, the No. 4 ESS, AT & T continued its post World War II leadership in electronic switching. However when it came to applying these principles to the local central office, they initially lost this leadership. How did this happen?

1.2. Between the ESSEX experiment and the decision in 1969 to proceed with the development of No. 4 ESS toll as a time-division digital switching system, several crucial studies had been made.

The first study came after the successful development of the T1 digital transmission system. The purpose of this research study was to evaluate the future (1970s) of integrated digital switching and transmission for the local areas (exchanges) in the Bell System plant as envisioned in ESSEX.

The second study in 1966 established a priority of toll over local for a new generation switch development to fit into an integrated digital plant. This eventually became the No. 4 ESS development. Many studies were made at this time to improve interfaces between space-division ESSs, No. 1 and No. 2, and digital transmission facilities that were then growing at a rapid rate, particularly in the short-haul trunk plant. A natural step was to develop a new tandem office system where these digital trunks would make up the majority of the terminations. On the other hand, for switching at the end of the network, i.e. at local offices, digital trunks constituted less than 20% of the total terminations.

1.3. AT & T's failure to bring a local time-division central office system onto the market was not from a lack of interest in the problem. In 1969 H.S. McDonald of Bell Laboratories proposed an interesting new architecture for local digital wire centers using VLSI technology. The first public papers were given on this system in the early 1970s (see Chapter VIII-3). These designs were unique in several ways, particularly with the addition of digital signal processing internal to the time-division network. Later, in 1979, an experimental Digital Switch (XDS) was built and used as a research model and testbed for new services.

1.4. Internal records at Bell Laboratories show that many studies were made in an attempt to capitalize on the No. 4 ESS design as well as other proposals to find a design that would compete economically with the highly successful No. 1 and 1A ESS space-division systems then being produced in a large quantity. It is often difficult to show new designs to be more economical than proven existing designs that have been refined and produced over a period of time. Under the monopoly situation that then existed in the Bell

System market, there was no need to rush an uneconomical design into production to assure continuing prestige in the industry. Unfortunately, the events of the early 1980s made a complete change necessary from this prospective.

1.5. In Canada and in the "independent" telephone companies in the United States, the well established traditional manufacturers for these markets, North (ITT), Northern Electric, Stromberg-Carlson were introducing local digital switches (see Chapters VIII-7 and VIII-8). From the prospective of the market place, including the great publicity that accompanied their introduction [1], these appeared to be successful developments. In many ways these systems were a success, except for the high unrecovered costs of their developments, the current high costs of the finished product and accompanying corporate losses, and to a lesser degree, technical difficulties in their applications. These were the very reasons why AT&T had held back.

1.6. The deployment of these early switches caught the attention of not only the industry as a whole, e.g. at the Paris ISS 1979, but also among the industry regulators in the United States who began asking the Bell Operating Companies (BOCs) why they were not applying such switches. The response was mixed. Some BOCs had bought and installed token switches from these manufacturers just for the "experience". Some said the switches showed no current technical or economic advantage over switches that they were then purchasing.

1.7. In some cases, in order to better understand these products and how development of an internal Bell Laboratories design might be justified, AT&T with the help of Bell Laboratories evaluated these systems, provided technical requirements and otherwise aided the BOCs by working with their manufacturers.

One supplier whom AT&T worked with was Northern Electric. Through stock ownership in Bell Canada, AT&T had for many years shared technical information with Northern Electric. As a result, a Bell System design specification for the DMS10 system (see Chapter VIII-8) was produced and BOCs then felt more confident to purchase these non-Western Electric switches, since they had what was expected and which met the requirements of AT&T and Bell Laboratories. (AT&T also produced a specification for the DMS200 time-division digital toll switch for use in their own long distance network where switches smaller than the No. 4 ESS and some No. 1 ESS designs were required.)

1.8. By the late 1970s it was obvious to the managements at AT&T and Bell Laboratories that deeper exploration of local digital switching as a prelude to development was necessary. Use of the elements of No. 4 ESS were restudied but with little positive results. Many new ideas were proposed and evaluated.

In March 1977 an intensive three day study by leading experts in the forward looking work at Bell Laboratories produced a new basic architecture for a local digital switch. The principal new element was the use of distributed switching as well as extensive distributed control. The remainder of 1977 was spent examining the application of the new system, now designed the No. 5 ESS, to various office situations, the underlying economics and possible development funding. First public mention of the system appeared in early 1978. By 1979 a planning letter on the system was sent to the BOCs. Shortly thereafter, the initial development case was authorized.

Within the same time frame, under increasing regulatory pressure to allow others to supply switches to the BOCs, AT&T's Purchase Product Division (PPD) placed a "request for quotation (RFQ)" to all possible suppliers of small offices. All but Western Electric responded with local time-division digital switches.

[1] Thus began the great era of hype with terms such as "Digital World" and "Digital Century" and misnomers such as "Digital Switching" becoming the grist for the advertisers mill and disparagement of space-division systems by calling them "analog". Not since the great debates of the 1910s on full automatic ("Lock Them Up and Leave Them Alone") versus manual or semi-automatic switching had the trade periodicals and other advertising opportunities been used to initiate and perpetuate competitively inspired technical inaccuracies.

1.9. Had it not been for the foresight and pressure brought about by the presence and apparent success of independent manufacturers in this field, AT&T might not have entered into the post-divestiture era, starting in 1984, with a competitive product well underway.

1.10. The initial No. 5 ESS was developed and completed in less than three years after the development was authorized. The initial installations of this system were what might be called "token" systems. There were two in 1982, of only 2,000 lines each.

The first cutover of a No. 5 ESS was in Seneca, Illinois, on March 23, 1982. By the time the initial development of the system was being concluded and large scale production was under way, there were six other switching systems in production in North America with an impressive 3.5 million lines in service [1]. (A seventh system, the No. 5 EAX was to come on-line later in 1982 (see Chapter IX-4)). Also, by this time the French E10 system had been sold around the world for over 12 years with about 2.7 million lines in service. The French were well ahead with their next switch design, the E10B, which had its first cutover in 1980 (see Chapter VIII-3, section 2).

1.11. As presented in more detail below in section 4, by the end of 1985, 8.8 million lines of No. 5 ESS for 770 offices had been shipped. The number of lines in service was 5.2 million. By mid-1986, No. 5 ESS had passed the DMS100 system of Northern Telecom for the number of lines in service.

2. The Product

2.1. The "Switch Module" (SM)

A basic element of the system is what is now called the "Switch Module" (SM). It is to this module that analog lines and trunks and digital trunks are connected. Each SM provides switching of a maximum of 510 time-slot channels.

The SMs are unique in that they contain a complete time-slot interchange (TSI) switching stage giving the modules the attributes of both distributed switching as well as distributed control. The first two central offices in service were single module systems. The first multimodule system with the first "generic" program, labeled "5E1", was not installed until August 1983 in Sugar Grove, Illinois. Initially the system could serve only 30 SMs. Taking into account the microprocessor then used in the SMs the system could service 150,000 BHCAs. By 1985 the maximum number of SMs was increased to 192 and the BHCAs to 300,000. In November 1987 AT&T quoted the No. 5 ESS capacity as "rated busy-hour call completions" at 650,000 BHCAs. 95% of the call processing is in the periphery.

The termination capacity of an SM is based upon the characteristics of the traffic of the lines and trunks connected to it. The number of SMs in an office is determined by traffic requirements. The maximum size of an No. 5 ESS central office, with a typical mix of lines and trunks, is a "nominal 100,000 lines" capability.

2.2. A "gated diode" crosspoint concentrator ahead of Borscht circuits

One element of the No. 5 ESS that elicited much comment in the marketplace was the use of a new solid-state technology, with a space-division line concentrator ahead of the BORSCHT circuit in the SM. By sharing a BORSCHT circuit among many lines its cost and service-affecting troubles could be spread. The use of this concentrator reduced the space requirements of the line units in a reduction range of 57% to 73%.

The concentration ratio was from (two to eight) to one. The solid state crosspoint element had capabilities much like a relay in that it could carry voltages and currents associated with regular telephone sets and lines [2]. It was known as a "Gated diode" crosspoint (GDX), similar to one then under development in Japan [3].

2.3. Catch-up in Services and Features

At the time the development of the No. 5 ESS was started, the No. 1 ESS included the capability – mostly implemented with software – to

provide over 800 service and features. These services and features had been developed during a period of more than 15 years.

The extensive reliance upon software is very helpful in the development of a new electronic switching system. Among other things it means that, once the basic architecture and instruction set are agreed upon, the hardware and software developments may proceed more or less independently. With an initial development period of about three years, the software development is limited to the number of persons that may be reasonably applied to the project. This then limits the number of services and features that appear in a new switching system when it is first marketed.

Catching up to a "moving" target is not a new problem. When the No. 1 ESS was first cut-over in 1965, the No. 5 Crossbar had a list of more than 500 services and features (see Chapter V-1, section 2.5). Under the competitive conditions now prevailing in the Bell Operating Company market and the guidance these companies obtain from the LSSGR (see Chapter IX-3, section 3), it is now possible to come to an agreement with the companies on what services and features they would approve for their initial purchases of systems.

Since the No. 5 ESS was late onto the marketplace, it did not catch up with services and features until after 1985. For a brand-new system, as it was in this case, being late onto the marketplace may have been, however, advantageous in that the system design employed architectural concepts and new technology that had become available since the first generation time-division digital switches were introduced.

A unique problem occurred with the development of the services for this system. The local telephone companies already had deployed more than 2000 large space-division SPC offices. The architecture of these systems was different from the No. 5 ESS. As a result, when the programs were written for the same services they operated somewhat differently in details. Many programs were issued before these differences, (or lack of "transparency", as it has now become known), were discovered. Eventually, after several years, these differences were reconciled. As more competitors enter the marketplace with different system architectures these transparency issues are likely to become a greater issue in the future.

2.4. *Obtaining the proper balance*

In a switch that combines distributed and centralized SPC processing, it is first necessary to choose where the variety of signaling and call processing functions will be performed. This choice is made to obtain the objective balance between hardware and software, a choice that distinguishes most 2nd generation switches from one another. In the No. 5 ESS, extreme flexibility is provided in the peripheral switching modules. Not only can each SM serve different line-, trunk-, data-, and signaling- ports but the same degree of freedom is provided in the controlling software.

The key to the software flexibility is the provision of an operating system environment that permits software to be moved as needed between the periphery and the central administration control module (AM) [4], even when located in a remote switching unit. The No. 5 ESS operating system was written in the C language and is now known as the OSDS (Operating System for Distributed Switching).

A careful choice was made in deciding upon the processors to be used that would function with the distributed software. For the main processor in the AM there was little doubt on the processor to be used. The 3B processor [2] had been under development for use as a replacement for the 3A used in the No. 2 and No. 3 ESS

[2] The 3B processor is available in different sizes and configurations for a wide variety of switching and computer applications [1]. For use in the public switched network the current version, "20", duplicated, i.e. "D", is used in No. 5 ESS and other switching system applications. Like the 3A processor, the 3B is highly reliable and fault-tolerant with not only micro-matching between duplicated portions but also with internal self-check circuits. For the software operating system, a version using UNIX programs in the portable C language and known as DMERT (Duplex MultiEnvironment Real-Time) was developed. The entire complex, hardware and software, is 3B20D/DMERT.

and as an attached processor for the Nos. 4 and 1A ESS [5]. The version of the 3B processor family chosen for the No. 5 ESS AM was the 3B20D. The first application of the 3B20D version was in the Network Control Point (NCP) portion of the common channel signaling network in September 1981 (see Chapter X-6).

A large number of microprocessor and digital signal processors (DSP) are used throughout the No. 5 ESS. As programming progressed, microprocessor types were changed several times. They were those made by a number of different manufacturers, including those of Western Electric. In 1985, the microprocessor codes used for various SM functions included the Motorola 68000, the Intel 8086, 80186 and 80188, the Western Electric 8000, and AMD 2901.

The memory requirements for programs and data bases never stabilizes, particularly in America where the large number of services and features required by the BOCs, like entropy, increase continually. However the processors chosen can accommodate very large random access (RAM) memories as well as disk memories for the 3B20D. The No. 5 ESS was the first switching system in production to use dynamic RAM chips of one megabit.

2.5. What was different? – Architecturally, technologically. Software advantages of being late, not "all digital"

As indicated above, much new hardware and software technology has been used in the No. 5 ESS system: optical links, GDX crosspoints, DSPs, OSDS, etc.

Because of the presence of the GDX crosspoint concentrator in the system, competitors with pure time-division switches did not wish potential purchasers to consider the No. 5 ESS to be in the same league or generation as their systems [3]. However, as a result of using this crosspoint in the initial system design, and particularly with respect to floor space and power advantages, the system competed on a price basis with the DMS systems that had already attained high production levels and markets. Besides its advanced technology some were attracted to the No. 5 ESS system by the simplicity of its architecture.

2.6. Flexibility and Adaptability

Once the initial system design made its successful entrance onto the marketplace, the designers set out to demonstrate its flexibility and adaptability. The emphasis in the lead article of reference [6] is that No. 5 ESS is a "single system with multiple applications": local, toll, operator services, PBX, private networks, and for metropolitan, suburban, and rural networks.

2.6.1. Local / toll

The first local/toll system with "equal access" features was placed in service in Harlingen, Texas, in January 1985. A new digital carrier trunk unit (DCTU) interface was developed to make it more economical to terminate digital carrier systems, including subscriber line carriers, on the switch.

2.6.2. Remotes connected by copper and optical fiber plants

The importance of remote switching to the second generation of time-division digital systems has been dealt with in Chapter IX-2. From the beginning of the No. 5 ESS development, this application had been anticipated. The SMs connect to the time multiplex switching (TMS) network through fiber optic links for network control and timing (NCT). Two of these links for each SM provide a total of 512 time-slots of 16 bits, which requires each link to transmit at a 32 Mbits/s rate.

Remote switch modules (RSMs) using regular T1 digital carrier links were first installed in Brokenburg, Virginia, in April 1984. Seven months later, in November 1984, the first optical-fiber linked RSM was introduced in Rochester, New York State.

[3] It is interesting to note that the French E10 system, with electromechanical crosspoints in the concentration stage, did not run into these kind of difficulties when it was successfully sold throughout the world some ten years earlier. The "GDX" crosspoint made the system "totally electronic" to quote the Japanese [3].

Nominally, the RSMs were to be located no more than 15 miles from the host. In exceptional cases, they were deployed as far as 100 miles away. The optical remote modules ("ORM"s) could be located as far as 45 miles from the host without repeaters, thereby giving a considerable advantage over the use of digital subscriber carrier systems. By January 1986 a cluster of several colocated RSMs in Inwood, West Virginia, were converted to a host office by the addition of an administrative module and TMS.

Digital remote switching units once available with efficient digital transmission interfaces proved to be very popular as a replacement vehicle for the many small community dial offices (CDOs). These offices are found in large numbers throughout the great sparse expanses of the United States. RSMs and ORMs, as well as similar developments for other time-division digital switching systems, have accelerated the deployment of these switches. By the end of 1989, AT&T had shipped 1863 RSMs and 249 ORMs, more remotes than hosts (1650). Clusters of RSMs can serve as many as 16,000 lines, which is sufficient to replace even some suburban offices.

A unique feature introduced in June 1989 at Colesville, Maryland, is the ability of remote SMs to have trunks to RSMs of offices other than the host, or to other RSMs in the cluster.

While the 10A RSS (see Chapter V-1) was under development, there was some thought as to making it an "on premises" switch for a Centrex host. At the time Centrex service was not in great favor due to regulatory constraints that required tariffs to be set for full cost recovery. After AT&T's divestiture, the RBOCs could no longer lease PBXs to their customers. Central-office-based Centrex was the only way the RBOCs could serve the business customers directly. After some regulatory intercession, RBOCs finally were allowed tariffs that enabled Centrex service to compete with on-premises PBXs. No. 5 ESS remote switch units could be placed on customer premises to provide Centrex service more economically by reducing transmission costs and providing intra-premises switching.Another application of RSMs is to colocate one or more RSMs with an existing installed space-division SPC switching office to provide not only additional capacity, but also services and features for which the installed system is not capable. This is called "capping" (i.e. to place a topping on the existing office). Since extensive call screening or directory number changes are required for this approach, it has not been very applied very often.

2.7. *The ISDN story [7]*

There have been a number of successful developments of SMs for various applications. One new SM uses an *integrated services line unit* (ISLU) and *packet switch interface unit* (PSIU), locally and in remote SMs, for ISDN and other new services.

- The ISLU SM unit is the foundation to interface ISDN digital subscriber lines (DSLs), with a maximum of 1536 DSLs per SM. The ISDN SM unit takes the place of a SM unit used for analog lines [4].
- The PSIU of an ISDN SM unit gives the system the capability of accessing a packet network from the D channel of a digital subscriber line and of allowing packet-data transmission on both the D channel at 16 kbit/s and the B channel at 64 kbits/s of the digital subscriber line. So claimed, No. 5 ESS became the first "only truly integrated packet switch" on the market.

With much fanfare, the first No. 5 ESS office with ISDN capability was placed in service at Oakbrook, Illinois, on December 16 1986 [8]. Along with the systems of most of the major switching manufacturers, it was demonstrated in association with ISS 1987, in Phoenix, Arizona, in March 1987.

In March 1988, the first multi-user ISDN equipped ESS 5 office was cutover in Dunwoody (a suburb of Atlanta, Georgia), to serve five important customers, each of them with a large number of terminals on their premises. These customers used the switch with both ISDN and CENTREX services. Like the AT&T PBX

[4] Standard ISDN features include the ability to address up to 8 terminals on the customer's premises served by a digital subscriber line.

products, their equipment included an interface with an application processor, called a unified adjunct switch application interface (ASAI), providing electronic directory service, centralized message service, and other similar data-bases available to CENTREX customers.

The development of ISDN capability for No. 5 ESS placed it well ahead of all central office systems in ISDN deployment. By October 1989, ISLUs were installed in 671 offices, with a potential service to 14.8 million lines and ISDN operational service in 185 offices equipped with over 325,000 digital subscriber lines. It has been said that while others held trials and gave demonstrations of what they would do in the market to provide ISDN when the demand materialized, AT&T was out selling the system, including terminals designed by them as well as by other vendors.

Even an independent telephone company, GTE of Florida, installed a No. 5 ESS with ISDN capability.

2.8. *Operator Service Position System (OSPS) [9]*

The Integrated Service Line Unit (ISLU) of an ISDN SM is the foundation not only to interface ISDN digital subscriber lines but also for an Operator Services Position System (OSPS).

At divestiture AT&T acquired most of the "independent" traffic service position systems (TSPS) (see Chapter V-1, section 6). Later, after a court decision, the regional BOCs (RBOCs) were allowed to establish their own operator service capability. The Northern Telecom TOPS system (see Chapter VIII-8) could be used with time-division digital switching but the TSPS was based upon space-division technology. As a result TOPS systems were initially purchased by the RBOCs as part of their operator service "takeback" programs.

A unique application of the ISLU for ISDN capability of an SM is for operator services. Bell Laboratories engineers realized that in effect an operator position is an ideal example of an ISDN service. Thus was born the OSPS, *Operator Services Position System* [2] as an optional feature of the No. 5 ESS. It was the first commercial system to use the ISDN Basic Access simultaneously for voice, data, and signaling.

The Remote Switching Modules could also be equipped with ISLUs for ISDN. This particularly enhanced the application of ISDN for Centrex and operator services. The first OSPS application was for directory assistance in Panama City, Florida, in June 1988. The first remote ISDN unit for operator services was cutover in September 1986 in St Louis, Missouri.

3. Marketing the System – a first for AT&T

3.1. *Competition*

The No. 5 ESS development was the first time that AT&T had to market a system in a competitive environment. AT&T had much to learn about such things as advertising, exhibiting, press relations, high level executive response and presence in dealing with customers, and customer support in general.

These lessons were learned slowly and only after many changes in the organizations and relationships that formerly existed within and between Bell Laboratories and Western Electric. Markets had to be defined and techniques developed for approaching customers and keeping track of them.

In the eyes of many in the industry it has taken longer than expected for AT&T Network Systems to become competitive. No. 5 ESS is an excellent example of this progress. At the time of writing (1989), AT&T is now considered by those in the industry as well as their customers, to be a fully fledged and formidable competitor.

3.2. *RBOCs "Free-at-last"*

Not only was the No. 5 ESS late to market and higher in price, but initially, as the new switching system tried to be sold, some unexpected and hostile receptions were encountered at the nascent regional RBOCs. Some attributed this effect as a RBOC reaction to the many years that AT&T had dominated its subsidiaries and dictated its will to them.

While there appeared to be little doubt about the advanced nature of the system and its promise for the future, many RBOC executives wanted to learn for themselves what the competition had to offer. It took several years before AT&T regained the confidence of the RBOCs. Most of the RBOCs eventually bought No. 5 ESS switches. But in the interim Northern Telecom was able to place DMS100 systems in office locations critical to the growth of future services.

3.3. *A schizophrenic process*

Another problem in selling local central office systems to the RBOCs is that, to some extent, AT & T was competing with its potential customers. It was promoting No. 5 ESS as a Centrex vehicle to the RBOCs while at the same time it was selling modern digital PBXs competing with the RBOCs for their potential Centrex customers.

Furthermore AT & T was designing the toll/tandem version of the No. 5 ESS for its own interexchange network while at the same time it was trying to sell the same system to the RBOCs to be used as a Intra-Lata tandem offices. This same situation existed for other products such as packet switching systems and signaling system No. 7 products (STPs and SCPs, see Chapter X-6).

3.4. *An "International Switch"*

The international posture of AT&T in switching aims at specific countries. While there have been failures, in general it is a success story since sales increased and AT&T acquired much of the experience needed to develop services and features peculiar to many different countries.

The No. 5 ESS "export" development was distinct from the United States No. 5 ESS development. Separate groups in the United States worked closely with groups in the joint venture company (see section 4.2 below), APT, in the Netherlands. Generic programs, a practice of approximately yearly issues that started with the No. 1 ESS development, are also used for the No. 5 ESS. By 1989, the latest generic program is the "5E6", indicating five previous issues. Separate generic programs, such as a "5EE2" where the extra E stands for "export", were issued for the non-US systems.

New features for the export systems were developed for pulse metering, international gateway operation, etc. In addition, the other features, such as ISDN, Centrex and intelligent networking, were offered to administrations anxious for such innovations.

3.5. *American Government Orders*

The domestic military service network in the United States, known as CONUS AUTOVON, originally included 45 No. 1 ESS four-wire switching offices (see Chapter V-1). Twelve of these offices were replaced with No. 5 ESS offices programmed with Autovon features. Through PBXs, they serve approximately one million stations at 800 locations.

In a competitive bidding, AT&T was awarded a contract in October 1986 to design and install 25 Voice Switching and Control Systems (VSCS) for the US Federal Aviation Administration (FAA). The basis for this design was the No. 5 ESS arranged with special hardware and software features required for the civilian air traffic control system.

3.6. *The Remainder of the United States Market*

While AT&T's principal customers were the RBOCs and foreign administrations, United States "independent" telephone companies also bought and installed No. 5 ESSs. The needs of the independent companies were generally for smaller offices, from 100 to 5000 lines. At this end of the market, Northern Telecom, Stromberg Carlson and ITT-North had enjoyed successes with their smaller DMS 10, DCO, and 1210 switches. No. 5 ESS switches are known in 1989 to have been sold to the following independent companies: Rochester, Alltel, Carolina Tel., United Telecom, and GTE (also see section 2.4 above). While the system was sold to independent companies for local applications, it was also sold as a toll switch to the operating branch of

AT&T for its national interexchange network. The first such switch was placed in service in Harlingen, Texas, in January 1985. By the end of 1989, 24 No. 5 ESS5s were in service in the long-distance AT&T's network in locations where the great capacity of No. 4 ESS was not required and where unique No. 5 ESS features are an advantage for their private network customers.

4. No. 5 ESS Acceptance

4.1. In the domestic market

In the US domestic market the No. 5 ESS assumed it place of leadership after about 3 years. By 1988 it had 49% of the sales versus 35% for Northern Telecom. This acceptance, principally by the RBOCs, was due to better service and performance. More recently the last barrier to its wide acceptance was broken down when the system became price competitive. By the end of 1989 it is expected that there will be more than 30 million lines in service in more than 1300 host offices. More than 1600 hosts and 2100 remotes have been shipped. Offices with more than 85,000 lines are in service. In 1986 more than 7 million lines were shipped, over one million lines every 7 weeks.

The provision of services and features has caught up with the long list of LSSGR requirements (see Chapter VIII-8).

Northern Telecom had introduced a demonstration office at their factory for experimentation and verifying services by their customers. They called it "First Applications Systems Test" (FAST) (a later version "FAST II" was provided for the Supernode version of this system). Not to be outdone, AT&T established at their software center their "Feature Interactive Verification Environment" ("FIVE") [12]. In addition, to help ISDN terminal equipment vendors confirm the validity of operation of their terminals with both the "basic" and "primary rate" ISDN accesses, a "Features, Applications and Capabilities Testing" (FACT) Laboratory allows to check the service capabilities of the various types of digital subscriber lines (DSLs).

At its peak, 3000 AT&T people were dedicated to the development and support of No. 5 ESS, more than half at Bell Laboratories. Instant customer service was given over a 24 hour hot line.

4.2. In foreign markets

As indicated in section 3.4 above, AT&T targeted entry points into the international markets for all products, but were particularly careful in choices for the No. 5 ESS considering the high stakes for a central office switch.

4.2.1. Even before the first domestic No. 5 ESS had been cutover in 1983, AT&T International started to market the No. 5 ESS overseas. Coincident with divestiture came the formation of the joint venture of AT&T and Philips (see Chapter XI-5), later known as APT. Since AT&T has now increased its share of ownership in APT, and Italtel has been added to the joint venture, it is now known as AT&T Network Systems International B.V.

Part of the joint venture of APT was to use the No. 5 ESS in place of the digital version of the PRX system. Philips had found that the development of this system was proving to be too costly to go it alone. Therefore, as in most joint ventures, both parties found an advantage. To assist in the marketing where the PRX-A system had been successful (see Chapter V-11), the international switch was called "5 ESS-PRX" [10]. APT's first success was the sale of nine switches to Saudi Arabia. The first of these switches was cutover in Lasliki, Saudi Arabia, in July 1985. This sale of nine exchanges launched APT onto the international market place.

In addition to Saudi Arabia, APT has sold the 5ESS-PRX system in the Bahamas, Columbia, Netherlands, Indonesia, Singapore, China (PRC), British Telecom in the UK, and containerized exchanges in India.

In the Netherlands the Dutch PTT, after certifying the 5ESS-PRX, continued its orders for the system in place of the PRX-D for which

they had made an earlier commitment. The first No. 5 ESS-PRX was placed in service in Nijmegen on November 19, 1985. Orders have been placed by the Dutch PTT for over one million lines. The largest office outside the United States to date is in Amsterdam with more than 38,000 lines.

A joint venture of AT&T and Telefonica, initially established for semiconductor production, has since sold a 5ESS-PRX to be produced in Seville for the 1992 Olympic Games in Barcelona.

The sales to British Telecom included a signaling system No. 7 network with SCPs and offices especially programmed for an initial application for what was called the "Digital Derived Services Network" (DDSN) [11]. This network, with service starting in November 1986 in Manchester, included 9 switches, 2 NCPs and administrative systems. In addition to this "Freephone" network, as it was called, APT contracted to deliver Centrex exchanges to British Telecom but later this order was canceled because of "expected delays in reconfiguring the switch to meet British standards."

4.2.2. In Asia, a joint venture with the Directorate of Taiwan Telecommunications and others established the "AT&T Taiwan Telecommunications", owned 70% by AT&T, with a plant in Hsin Chu. More than 125 No. 5 ESS switches have been made there for the local market.

Another AT&T joint venture in the switching area in Asia is with Gold Star Semiconductor in the Republic of Korea. Initially they manufactured ESS No. 1A. Later they started to introduce No. 5 ESS.

Also in Asia, Singapore purchased No. 5 ESS switches. They required a degree of flexibility in software not previously made available to customers. In addition, the first No. 5 ESS international gateway, including traditional gateway features such as call booking, was installed in Singapore.

AT&T has also had success with sales in the People's Republic of China, viz. for China National Instruments Import and Export, for the Ministry of Railroads and the China Electronics Systems Engineering Co.: the first of these offices, Wuhan, was cutover in December 1986.

4.2.3. At the end of 1989, 92 host offices with 106 remotes were in service outside of the United States, serving nearly 900,000 lines and about the same number of trunks, an indication of the presence of many tandem or gateway offices. About 75% of these lines were in service in Europe, once considered an impenetrable bastion of nationalist markets.

5.. Conclusion

When the final story about AT&T's No. 5 ESS will be written, it will show that, based upon sales, this second generation time-division digital switch was most successful and represented what is called in the United States a "late bloomer". So far, the architecture of the system, conceived by a committee in three short days, has proved to have the necessary ingredients for meeting the many and changing application challenges of the 1980s. Despite many disparagements about the initial switch not being truly time-division, the designers as with many successful second generation switches expect to continue to demonstrate the system's adaptability to new technology into the 1990s. AT&T's success to date (1989) with the introduction of ISDN has demonstrated not only their technological but their business skills and their preparedness for the future in a highly competitive industry.

There is no question that the considerable experience of AT&T's development managers was a factor in this great recovery. It is interesting to note that other system entrepreneurs have not always taken lessons from the experiences and techniques that AT&T employs [13]. Perhaps as AT&T enters deeper into the competitive fray, they will no longer enjoy the luxury of this type of project management.

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CHAPTER IX-4

THE AMERICAN GTD SYSTEM

1. General Telephone's initial digital contribution [1]

1.1. No more EAX, but GTD

The code change started with time-division digital PBXs. The first of these PBXs was the GTD-120, introduced in 1975, where GTD meant General Telephone Digital. But work had been underway at the Automatic Electric Co. since 1969 on a time-division digital toll system. Following its space-division mates, this system was initially called the EAX No. 3. It was not until it was time to develop a local time-division digital system that the GTD acronym was retroactively applied to call the No. 3 EAX the "GTD No. 3 EAX".

1.2. GTD No. 3 EAX, a toll/tandem office system

As with most entrants into the digital switching fray, General Telephone and Electric Company (GTE) determined that their initial project should be a toll/tandem office. The development was assigned to their manufacturer and laboratories, Automatic Electric Co. Since GTE was the largest independent company, they closely followed the developments of the Bell System. So it was not suprising to find them embarking on a digital switch when AT&T announced the development of their toll/tandem digital No. 4 ESS.

The architecture of the system was somewhat different than the AT&T No. 4 ESS approach. Like the Vidar IMA switch, it employed a S-T-S network with 9 bits in parallel but with 193 time slots (1.54 MHz). The network was capable of serving 16,000 trunks. They proposed that larger offices be served with multiple units coupled by the use of interunit common channel signaling. This kind of proposal has been made by several system architects but has never been put into practice.

The processor used in the system continued the use of the processors that had been used in the EAX 2 space-division system. Initially this was the 2A processors used in 4 pairs with a capacity of 360,000 BHCAs, and later the 2B processors used in 7 pairs to offer a capacity of 700,000 BHCAs.

The first cutover was in Rice Lake, Wisconsin, 1978 with 1,500 trunks. No more than 50 offices were installed with a total of less than 200,000 trunks. The system was modified in 1982 to provide common channel interoffice signaling (CCIS) [2]. The first office operating with the CCIS feature was in Fort Wayne, Indiana, in November 1982. The only known export sale of this system was to Puerto Rico.

1.3. International version of GTD No. 3 EAX [3]

The design of the No. 3 EAX was exported to Italy where the GTE's marketing subsidiary, Italcom, modified the design for the European 32-channel 2 Mbit/s standard. This system was called the GTD-3 EAX-I (I for international). The first of two Italian exchanges of this type was cutover in Genova during the second half of 1982.

2. The local system – GTD-5

2.1. Success with PBXs [4]

The pattern of GTE local digital switching developments is similar in many respects to the AT&T story but with one major addition. Like Bell, GTE already had successful space-division SPC systems in production and their designs were undergoing continual improvement and expansion.

The different element in the GTE approach to local digital switching was their success with digital PBXs, first with the GTD-120 and then with larger systems, the GTD-1000 and GTD-4600. The latter system had a capacity of 1000 to 4500 extension lines. A later version, the GTD-4600E, doubled this to 9200 lines.

The first of these systems was placed in service in 1978. Like AT&T, GTE had the advantage of a captive market in the GTE operating companies. As a result the PBX system was well received and more than 100 switches were sold in the five years following its introduction. It was used as a Centrex on customer premises, e.g. serving an entire building with offices for many companies.

The system was exported to South America and equipped with CCITT R2 signaling.

The most important development for the GTD-4600 started in 1979 and was known as the GTD-4600TSE. This version of the system was not only to serve as a large PBX but also as a tandem office for large private networks [2] with a network control center.

2.2. The need for a digital local central office. The AT&T scenario revisited with a major difference

GTE operating companies purchased the most part of their switching equipment from GTE Automatic Electric. Even more than the Bell Operating Companies, they were under pressure from the "independent" telephone system manufacturers to try their time-division digital systems as had other independent telephone operating companies.

Studies by GTE-AE Laboratories (GTE-AEL) indicated that time-division digital systems could not at the time compete economically with the space-division systems they were now deploying in quantity (see Chapter V-3). Despite their misgivings they proceeded in 1980 to develop a time-division digital switch that initially would be for the local office market. The new switch would be known as the No. 5. Eventually it would serve as the head of an entire switching system family.

For its architecture, GTE-AEL chose to build it upon the GTD-4600 PBX whose development had been started ahead of the local switch.

The local switch was to be known as the *GTD No. 5*. No explanation for skipping the series number 4 has ever been given except perhaps to avoid confusion with the GTD-4600 PBX. Also, by then AT&T was considering its local system which carried the number No. 5.

2.3. System description of the GTD-No. 5 [6,7]

The general architecture of the GTD-5 system is very similar to that of most of the 2nd generation switches described in this Part of the book. It offers a capability of serving a range of 500 to 150,000 lines with a codec (BORSCHT circuit) per line. Unlike the GTD-3, its switching network structure is of the T-S-T type. The traffic capacity is 18,333 Erlangs.

Speech samples are sent through the system as 12 bits parallel. There are 384 time-slots. The bus rate is 3.088 Mbit/s. The time-slot interchange portions of the switching network are in the peripheral modules. These modules were given names that related them to the types of transmission facilities to which they interface: analog lines, analog trunks, digital trunks, etc.

The stored program control resides in three places: peripheral processors, an administrative processor, and a central telephone processor. However, the initial software configuration required the central telephone processor to process most of the call details [8]. The initial system had a maximum traffic capacity of 360,000 BHCAs. The software is written in a version of PASCAL.

2.4. Success of the GTD-5

Production of the system began in October 1980. The first office was cut over in Banning, California, on June 26, 1982, three months after the No. 5 ESS. GTE-AEL had planned on a cutover in November 1981. But, in keeping with most of the industry, they were approximately seven months late.

Unlike AT & T after divestiture and its No. 5 ESS, GTE had a monopoly market and was able to sell their system to the GTE operating companies as fast as they could turn out the offices with the required features. Approximately 80% of their sales have been to these companies. Offices were also sold to non-affiliated independent telephone companies in the United States, particularly after the design received REA accreditation for low cost government loans.

By the end of 1988, 9.1 million lines had been installed and 20.4 million lines, shipped. The 10 millionth line was shipped in August 1988. By that time there were 1516 offices in service.

One million lines were in service in Canada where GTE has operating properties. GTE has a factory in Canada and therefore import taxes could be avoided. They sold to most large Canadian operating companies except Bell Canada who is affliiated with Northern Telecom.

Besides Canada, sales were also made in the Caribbean area and in Belgium and Italy. The system was adapted for the European market by the GTE subsidiary GTE-ATEA at Herentals, Belgium and the Italian GTE subsidiary (GTE Telecommunicazioni S.p.A.) in Milan. The system for these European applications is known as GTD-5C. The first installation was in Mons, Belgium, an exchange cutover towards the end of 1983.

A new line-card was developed by GTE-Italy for the European market. For a time, merger possibilities for GTE and Italtel were discussed. At the time of the merger talks, Italtel adopted the GTE line-card for its UT-10/3 system (see Chapter IX-9). There were even talks about this line-card becoming a universal line-card for all systems in Europe.

Foreign orders were received from Guatemala, Mozambique and Taiwan. Since GTE had manufactured systems in Taiwan before (see Chapter V-3), a technology transfer deal was made with them in 1985 to manufacture the GTD-5 system. This deal however was never finalized (see section 2.6 below).

2.5. Enhancements to the GTD-5

The GTD-5 system has been under continuing development since it was first introduced in 1982. Unlike the other systems competing in the American market, it did not have to meet the LSSGR (see Chapter VIII-8) requirements of the RBOCs. However, it had to provide for "equal access" (see Chapter V-1).

While GTD-EAX3 was relatively new, there was not much opportunity for an expanded market of the system. It was designed for large installations of which there were relatively few in GTE operating territories. Therefore it was decided from the start that toll/tandem capability should be developed for the GTD-5. The first GTD-5 toll office was cutover in Lafayette, Indiana, in June 1982. ahead of the first local version, once again proving that intermediate switching systems are a less difficult development and offer a better way to enter the digital switching business.

In keeping with the trends for second generation time-division digital systems, GTE also had to provide a remote switch. Such a switch, using some of the subsystem components of the central office design, was developed for use of up to 6,000 lines [9]. Its principal application was for CDO replacements, for which there were considerable needs in GTE territories.

GTE-AEL had not developed Centrex for their space-division SPC systems. As a result, wherever this service was needed in GTE territories, the systems were purchased from Western Electric. For the GTD-5, GTE-AEL did develop a form of Centrex for small business communities of from 6 to 2,000 lines, in providing what was called "integrated business services" that included many of the advanced features of PBXs (e.g. electronic tandem networking, least cost routing, etc.). A military version (in the form of a

large PBX) of the GTD-5 was placed in service in 1987 for the Naval Air Station in Whidbey Island, Washington State.

As far as enhancements were concerned, GTE-AEL provided for the system whatever was required by a particular customer to meet his service demands. It was not until ISDN came along that they had to incorporate features not yet requested by their customers. However, with ISS 1987 coming to Phoenix, their home city, GTE-AEL participated with the other manufacturers, US West, and Mountain States Telephone (the local telephone company), in demonstrations of ISDN capability of the GTD-5 [10].

A first ISDN field trial had been run in 1986 by GTE-AEL in using the time compression multiplex technique (the "ping-pong" method) for the digital subscriber line. It was about this time that they also decided to try to sell their system to the RBOCs. They paid Bell Communications Research (Bellcore) to run a first phase evaluation of the system. At the same time they also ran an REA field trial.

By the mid-1980s, the CLASS services (see Chapter X-6, section 6) – automatic recall, auto call-back, VIP alert, selective call accept, selective call rejection, selective call forward, originating customer tracing, calling number display, delivery blocking – were the second set of so called "customer calling features" being promoted by the RBOCs in the United States. They were included in the LSSGR requirements and all manufacturers were developing them. At about this time GTE-AEL also started to develop these CLASS services: they all depended upon the existence of signaling system No. 7 that was also being developed by GTE.

3. GTE Switching becomes an orphan

3.1. In 1987 GTE had decided to concentrate on the operating and services aspects of its business and to give up its worldwide interests in network products manufacturing. GTE sold its PBX interests to Fujitsu and, later, Siemens purchased most of the telecommunication equipment manufacturing properties of GTE: the transmission production facilities of GTE in the United States and GTE switching interest outside the United States.

From Siemens point of view the main object of its deal with GTE had been to increase its world market in switching. Siemens had hoped to include in this market much of the installed base of GTD-5 switches in the United States. Since GTE operating companies owned much of their equipment in this system, there was some concern about the GTD-5 future, in so far as Siemens would plan to merge and market it into its EWSD system. Try as they might, there did not seem to be any way that the two systems could find a common basis for a transition meeting Siemens' objectives. As a result of the impasse, Siemens only acquired GTE switching plants and activities outside of the United States, principally in Taiwan, Italy and Belgium. GTE retained its switching manufacturing plant in Phoenix, Arizona, where its GTD-5 system was manufactured. This left the Phoenix plant as the sole source of GTD-3 and GTD-5 for GTE. Design responsibility for these systems also remained there.

3.2. While the installed base of the GTD-5 system in the United States is large, continuing the design of features and services for the ever changing United States market is costly. This is particularly true when one looks ahead and finds that the market offered by GTE operating companies is an already a saturated market and that there is little likelihood of new markets opening for the GTD-5. In 1988 AT&T and GTE formed a joint venture, called "AG Communication Systems" (A for AT&T and G for GTE) to take over responsibility for the system "orphaned" by the sale of other network products to Siemens.

Initially the new company was only expected to call upon AT&T, particularly Bell Labs., for development assistance, but gradually AT&T had the option to purchase the entire company. Whether AT&T will be able to fold this system into its No. 5 ESS product line any better than Siemens could have done for its EWSD,remains to be seen.

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CHAPTER IX-5

SYSTEM X (UNITED KINGDOM)

1. Birth of a great project in a difficult environment

1.1. The development of System X was to both the British switching industry and the British Post Office (BPO) [1] the major project of the 1970s.

1.2. A difficult environment

1.2.1. In United Kingdom after many difficulties and much beating about the bush in the 1960s, there had gradually dawned a grudging realization of the problems facing Britain's telecommunications:

- aging of the organizational structures both within industry and in the BPO which then operated the public telecommunication services;
- the increasingly evident obsolescence of the step-by-step switching system used in almost every exchange in the British network. Industry went on churning out Strowger exchanges pending the indefinite advent of the future system, one which had to be both perfect and electronic, was constantly promoted but never seemed to materialize [2].

Cracks were starting to appear in the imposing and majestic edifice which British telecommunications offered to the gaze of the public at large. They were, however, visible to very few because, as in any other country, only a tiny circle of people were familiar with the mysteries of this sector which plays so special a part in the national economy. The initiated were after all highly competent people, though in most cases they had no real power of action.

1.2.2. No major decision could be taken outside an extremely tight chain of processes and, the higher up the ladder one went in the decision-making hierarchy, the less technically competent became the authority concerned:

- the telecommunication equipment industry depended essentially on orders from its Administration (GPO/BPO);
- the GPO/BPO's investment budget depended on decisions of Parliament (the GPO was not allowed to seek independent loans, much less to contract them abroad);
- decisions of Parliament depended in turn on the general economic circumstances which, in the medium term, meant a stop-go policy and, all too often, drastic cuts in the GPO/ BPO's investment programs.

Quite naturally, Britain's industrialists were wary of any initiative that might involve them in the sort of investment needed to develop a new technological generation of switching systems. Their manager's ambition was simply to retain the slice of the GPO order cake traditionally allotted to their companies, with the result that the innovations recommended by their excellent research engineers were inevitably swept under

[1] The name and sometimes also the status of the body responsible for telecommunications in the United Kingdom changed as a reflection of shifts in the parliamentary majority in the House of Commons. Thus, after the General Post Office (GPO), the BPO was instituted in 1969 as a public corporation. It was followed in 1979 by British Telecom (BT) marking the split between telecommunications and the BPO's postal and financial activities.

[2] The last Strowger public telephone exchange equipment supplied to BT was delivered in early 1985. Manufactured at the Edge Lane (Liverpool) factory, it was the last of a production line which began in the same factory on 1912 [1].

the carpet. Starved of competitive products, export markets closed one after another to the detriment of both the British economy and its balance of payments.

This sequence of causes and effects, sparked by the budgetary decisions taken in Parliament in respect of telecommunications investments, offered a perfect model of the vicious circle.

1.3. Realization of the situation

A whole series of official reports in the form of White Books, etc. criticized the situation one after another. Those whose recommendations met with most success included:

– in the case of telephone switching, the reports of an Advisory Group on Systems Definitions (AGSD) which was set up in 1968 as a think-tank between the GPO and its three main suppliers, namely Plessey, GEC and STC;

– with regard to the restructuring of activities of the BPO and Britain's telecommunications industry, the 1977 report by Prof. C. Carter [2] and the one submitted in 1981 by Prof. M. Beesley [3], both of which approached the problem from the broader national angle. Selected from among the country's leading economists, these two University professors were assigned the task of providing the Government and the Parliament with a thorough reassessment of the situation prevailing at the end of the 1970s, one which had remained static for too long and was considered unsuited to the technological and economic conditions of the time.

2. The AGSD and its deliberations

2.1. The thorny and protracted deliberations of the AGSD, and the implementation of its recommendations, served as the foundation for the development of System X.

The plodding progress made by the AGSD between 1968 and 1976 could scarcely be better summarized than it was by its head, L.R.F. Harris [4] in the introductory paper on System X, which he delivered to the 1979 Paris ISS.

A preliminary work of the AGSD had been to highlight the need for modernization of a British network dominated by 2-wire electromechanical switching systems and a multiplicity of limited capability inter-exchange signaling systems.

"Two basic tasks were then determined by the AGSD:

- the first, essentially technical, was to advise the Post Office on the (switching) system and subsystems that should be developed for the 1980s;
- the second was to advise on how best to reconcile innovation and competition in design with the standards necessary to interworking and effectiveness.

The need for a new relationship between the GPO and its switching manufacturers (the "second AGSD task") was clearly demonstrated by the AGSD. This relationship took time to establish because of the many difficult commercial problems that had to be resolved along the way.

When AGSD had been set up in 1968, it was at a time of significant change in the British telecommunication scene. The Post Office itself was about to become a nationally-owned corporation rather than an administration. Much greater emphasis was being placed on competition between the British equipment manufacturers, both in design and supply. New procurement arrangements were being developed. Collaboration in switching systems research and development was giving way to an arms-length relationship in system development, both between the firms and with the Post Office. Innovation in design was to be encouraged, and definitions and specifications for new systems had to be in no more detail than was necessary for interworking.

In this new situation, some notable successes were achieved; for example, the development of the TXE 2 and TXE 4 systems. However, it was soon realized that these conditions of intensive private venture were not well suited to the effective development of a complex telecommunications system in the British context. They led to a proliferation of equipment types in the Post Office network. Expertise became fragmented

over a variety of divergent private venture projects. And although there was no shortage of inventive ideas for the future, the individual companies – and the Post Office – generally lacked the resources to carry them through to a successful conclusion." [4]

2.2. It thus took no less than 7–8 years of prior deliberation, followed by discussion, before the necessary cooperation agreements for developing System X could be concluded between British Telecom and its three switching equipment manufacturers, namely GEC, Plessey and STC (the participating firms or "PFs" as they were officially called).

The magnitude of these problems may be judged by the delays encountered: the task of project definition did not begin in earnest until the spring of 1976, and substantive development work on System X was not launched until about a year later.

The expression "joint venture" springs readily to mind as a description of how this cooperation was organized. The term would not be appropriate, however, since it has legal and financial implications which did not exactly correspond to the approach adopted. Cooperation was organized on a far from equal footing since, as the chief financial backer and awarder of R & D contracts, BT was in the position of being the main client [3].

However, even if the development of System X was not a joint venture in the legal sense, it was certainly a big adventure and a professional challenge to the hundreds of engineers who, in the space of four or five years, succeeded in taking the first System X exchanges from the drawing board to the commissioning stage.

[3] An instance of its predominant role may be seen in the fact that, until System X was actually marketed, only BT engineers were allowed to draft articles describing the system, particularly for the POEEJs of the 1979–1981. With few exceptions, the same was true of the papers delivered to the ISS in Paris (1979) and Montreal (1981) and at other equivalent high-level meetings.

3. Wealth of documentation on system X

The existing documentation on System X is historically invaluable for several reasons:

1) it is both abundant and highly detailed;
2) it has the advantage of having for the most part been assembled in publications spread over only two years. Until 1979 there had been a virtual blackout on information, presumably reflecting an excessive desire to protect the research and development on system X. Only a few scraps of carefully leaked information on the System's main principles, its modularity and division into subsystems reached Britain's ever-watchful technical publications [4];
3) anyone wishing to know the details of System X can find them in an even more condensed and practical form in the compendium. published in 1981 [5] by the Institution of Post Office Electrical Engineers. This publication contains 25 articles by 37 authors, which appeared in the from January 1979 to April 1981 issues of the highly reputed POEEJ.
4) this mine of documentation is all the more interesting in that the articles are drafted in an academic and historical style without any trace of commercial or advertising motivations.
5) the 1981 compendium offers a faithful and well-documented reflection of the profound

[4] The almost military secrecy that was maintained for so many years in respect of System X led to some confusion or at least engendered a play on words as to the designation chosen. While the System's promoters obviously took the letter X to mean "exchange", many others – particularly non-English speaking people – took it as the symbol of "the unknown".
Another and fortunately rarer type of confusion arose from the fact that the letter X was interpreted as a Roman numeral, an error which was wittily pointed out by the British authority who presented System X for the first time internationally at TELECOM 79 in Geneva: he felt it necessary to clarify matters as to the system's designation after a leading foreign figure unfamiliar with switching matters had told him how much he was looking forward learning more about the System 10 he had heard so much about.

transformation that occurred in the 1970s concerning the industrial methods of producing a switching system: introduction of computer-aided design (CAD), automated drafting systems (ADS) and modern software generation methods, particularly through the use of a high-level programming language;

6) one equally interesting peculiarity of the technological developments that occurred in the 1970s is that the research and development of System X was carried out by four partners whose research laboratories and factories were scattered throughout the country. Situations involving such constraints were fairly rare at the time. A few other examples could be found in the telecommunication sector but they are rare, as in the case of the multinational corporation ITT's System 1240. The introduction of such a model of close cooperation and coordination between far-flung sites, requiring data transmission networks between computers, is characteristic of the 1970s [5]. Future technological historians having to describe the industrial changes that took place at the end of this century will certainly find invaluable evidence and extremely useful documentation in the articles on "Design and Support Systems" contained in the POEEJ collection.

Drawing upon the very best sources, the description of System X and of the phases of its development given below is based essentially in the POEEJ compendium [5] from which large extracts have been taken with the kind permission of its publisher.

3.1. While this Chapter might seem inordinately detailed in comparison with those on other switching systems that were even more widely used than System X, the author begs the reader's indulgence on the following grounds:

- the United Kingdom plays an important role in telecommunications;
- System X is an extremely representative sample of the ideas which prevailed in switching in the 1970s in that it lies midway between the major changes that then occurred in system design, i.e. the grafting onto a time-division SPC system of data packet signaling concepts (System No. 7), the use of CHILL-type high-level languages for the software, etc.;
- System X was a "committee" product and the descriptions of it faithfully reflected each of the reasons for or against a particular solution, ones which were discussed at length before any technical option was decided. The analyses put forward are thus bound to interest the switching engineer, if only retrospectively;
- lastly, as the joint property of two industrial groups, System X did not receive the same noisy publicity as many of about its competitors of the same generation; it therefore offers a perfect subject to be covered in full impartiality.

4. Guiding principles of the system

4.1. The fact that the managers of the BPO and their industrial partners took a long time to reach agreement on the joint development of System X offered at least one advantage, namely that the research engineers involved were by the end of it fully familiar with the design principles wanted. Their expert knowledge of the technical developments that had occurred between 1968 and 1974 (from the ISS in Paris in 1966 to that at Munich in 1974), combined with the chronology of events, enabled them to decide on the major options of their project without any hesitation whatever.

System X was an ambitious project in that it had to provide a modern system to equip the British network well beyond the end of the century and be internationally competitive enough to reconquer the country's lost export markets.

[5] A situation not peculiar to the telecommunication industry since both the aeronautical and aerospace industries were both widely engaging in such practices: NASA-coordinated research and manufacture in the United States and a similar approach in Europe for having the AIRBUS aircraft and the ARIANE space launcher produced by several European countries.

The system was therefore to be [5a]:

a) SPC. British misgivings about the SPC systems and their cost had now evaporated. Lower memory costs and ever-increasing storage capacities were looming and the successes of SPC systems outside the United Kingdom offered an equally decisive incentive;

b) Digital [6]. British engineers had pioneered time-division switching. PCM systems had been standardized in the late 1960s. The use of such systems for transmission was catching on in the United Kingdom and the economic advantage of the "synergy" existing when digital techniques were used in both switching and transmission was becoming obvious. Lastly, standardized PCM systems were giving digital switching the basic tool it had lacked during the early British research into time-division switching [7];

c) using the digital common channel signaling (CCS) concept, the one of the future CCITT No. 7, for both inter-exchange and intra-exchange signaling. Indeed, the years 1972 to 1976 were precisely those when the CCIT was engaged in the development of System No. 7 and British engineers were proving themselves very active partners in framing its specifications.

d) based on a modular approach. From the early 1970s, the principle of modularity had become the keyword in the architecture of switching systems, imposed as it was by the increasingly rapid development of electronic components and the need to be able to independently update hardware with the latest technology;

e) intended to develop a whole family of applications. In the family approach not only common design features but, wherever economically practicable, common hardware and software modules would be used;

f) allowing remote control of exchange functions to enable certain management and operational features of the network to be centralized for economy and improved service;

g) allowing concentrator working, with remote control to enable the SPC and CCS benefits to be obtained with small, dispersed local exchange switching units.

These basic principles, particularly those in a), b), c), and d) above, proved a perfect match for the aims set by the BPO and on which it had placed considerable emphasis [4]:

4.2. Another initial target for System X, that has also to be noted here, was to obtain a System X design suitable for export, a target which received the firm commitment and the strong support of BPO (and, later, of BT): during the design stage, export requirements often had to take priority over BT's views more specific to an implementation in the British network.

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[6] However, when System X was conceived, a fully-digital system was not still in view. At that time, the only practical solution for a local exchange was to use an analog concentration stage for the subscriber-line part of such an exchange. It was not even certain, initially, that the central digital switching network (the future "DSS") would be digital.

[7] "Early work by BPO on digital switching began in the 1960s and led to two field trial installations of pulse-code modulation (PCM) tandem exchanges: Empress in 1968 and Moorgate in 1970. At that time, PCM transmission systems were beginning to be introduced where they showed economic advantage over earlier analog transmission plant.

The purpose of the Empress and Moorgate experiments was to demonstrate the technical feasibility and economic viability of switching the speech while still in a digitally-coded form, which would result in the provision of less equipment and reduce transmission loss, noise and distortion.

Both exchanges successfully met their objective, the main difference between them being that Moorgate was processor controlled while Empress was not. This success, combined with subsequent advances in technology, led to consideration of digital switching for local exchanges as well as for junction and main-network switching centers. The result is that all System X exchanges will incorporate digital switching." [5a]

5. Modular structure of the system. Its use for the distribution of research

5.1. The emphasis in the design of System X had been to provide a series of modules, both hardware and software, as "building blocks" which would permit the provision of the System X range of exchanges. Modular units in the standard set were referred to as "subsystems".

Subsystem boundaries were chosen to exploit the latest technologies available at the time of design and to facilitate the introduction of further technological advances in the future. The interfaces between subsystems were to be of so enduring a nature that, after initial definition, agreement and refinement, they would remain unaffected by any subsequent change in subsystem design.

5.2. The principal hardware subsystems of System X are the following:

* Digital Switching (network) Subsystem
* Processor Utility Subsystem (a complex of several processor units providing the data processing facilities for handling traffic and controlling Switching Subsystems)
* Message Transfer and Common Channel Subsystem
* Subscriber Switching Subsystem (concentration function) and
* Analog Line terminating Subsystem (conversion analog/digital)
* Signaling Interworking Subsystem
* Network Synchronization Subsystem

Most of these subsystems have software handlers that run on the processor as part of the total system software.

5.3. The principal software subsystems are the following:

* Operating Subsystem
* Call Processing Subsystem
* Maintenance Control Subsystem
* Man/Machine Interface Subsystem
* Overload Control Subsystem
* Call Accounting Subsystem

Software subsystems are stored and run on the Processor Utility subsystem (a hardware subsystem), under the control of the operating subsystem. The principal functions of the Operating subsystem, placed at the top hierarchical level of the software subsystems, are the traditional ones: job scheduling, storage allocation, fault detection and recovery mechanism.

In each subsystem, software, in accordance with the System X terminology, is divided into one or more *processes*, each of which is made up of modules. Each process is a software security unit required to be confined to the storage and input/output (I/O) hardware allocated to it [5c]. Each process has a limited area of access to the main memory which stores dedicated programs and data.

The process is the only software unit which is identifiable for scheduling on the processors. It is the passing of messages (in System X terminology, the "tasks") between processes which indicates that a process has some work to perform. Tasks passing between processes are sent via the operating system which controls the access rights within the system [6]. The messages are routed via the operating system in such a way that the sending process only needs to know the identity of the receiver, not its location. Each message consists of a 4–8 word task which is linked into the receiving process input task queue [5d]. With this software decomposition, coupling between any two software elements is minimized. With boundaries drawn on a functional basis, processes and modules are self-contained and therefore easily understood from both the design and the maintenance standpoints.

A typical breakdown of the processor occupancy at full load can be seen in the following table (an assessment presented at the 1979 Paris ISS [6]):

Item	Occupancy
Call Processing	33%
Signaling	23%
Switch control	12%
Operating system	8%
Idle	33%

5.4. The basic modularity of the system's architecture was also used for distributing Research

and Development tasks between the Participating Firms (PF)s. Very broadly speaking, this meant that, at least initially: Plessey was responsible for the digital switching subsytem; GEC for the processor utility subsystem; and STC for the message transfer subsystem.

6. Architecture of System X

6.1. A family of systems

In its initial design, System X was intended to constitute a family of systems for covering the entire range of switching centers from the smallest concentrator-type local exchanges (less than 2000 lines) to the very largest (up to 60,000 lines), as well as all types of trunk exchange: combined local/trunk exchanges, small and large trunk exchanges and international exchanges.

When the system was put into production in the early 1980s, the first priority was that of equipping the trunk nodes of an overlay digital network for covering the whole of Britain during the decade in question. The provision of local exchanges was done in parallel but as a second priority.

6.2. More than a family of systems – an architecture

The term "family of systems" was probably not the most appropriate, particularly so far as its architectural principles were concerned. Indeed, M. Ward [7a] is both clear and eloquent on the subject:

"It is not so much a family of discrete exchange types as a family of multi-purpose subsystems all conforming to a common framework; *a set of building bricks* which can be assembled into a virtually unlimited number of switching systems. The common framework, *the cement* which holds the building bricks together, is composed of *the messages* which flow between the subsystems. It can be said that System X is defined by, indeed it actually is, its message structure. Everything else can change as long as the message structure remains constant..."

6.3. A trend towards a distribution of the control functions

6.3.1. M. Ward's description is highly significant since it pinpoints an essential feature of the System X architecture, namely a trend to distribute some functions of the control system.

6.3.2. This was one manifestation of a clear trend which mark many systems of the generation designed in the 1970s. In System X and a number of other systems, this trend was accompanied (or explained) by the generalized use of microprocessors which were now included among all the components that the switching industry had to shop for in a fast market. Large-scale mass-production made microprocessors available at extremely competitive prices and, in System X, they became associated with every hardware subsystem.

6.3.3. In the aspect of distributing some of the control functions, System X was rather novel, at least if we refere to the chronology of its advent and that of the appearance and placing in service of systems of the same sort, which in fact means two quite distinct chronologies: the details of a system are published only when manufacture is well underway, i.e. often several years before it is actually placed in service. In order to respect the confidentiality of the research, such publications should not appear too early; nor should they appear too late, however, if they are to pave the way for marketing a project [8].

In the architecture of a system, distribution of the control functions is indeed a major topic. There is, however, quite a large spectrum in the modes and structures of what in the 1980s has become "decentralized control". The structures of many systems boasting this feature offer only partly decentralized control: in these systems, a central processor (with duplication) is still here to work with peripheral processors (in some systems called the "regional processors").

[8] In this connection, see in [8] J. Meurling's highly pertinent reflections on the launching of the AXE system.

At the beginning of the 1980s, a fashionable trend in system architecture has been complete control-decentralization, the "fully-distributed processing" concept: multiprocessors, or even more microprocessors, are organized around a network of buses or links, with accesses to shared memories. In these systems, there is no longer any central processor acting as the master of the organization and in which reside the functions of task scheduling. The operating system functions are a matter of a software spread over process allocators implemented identically within the microprogram of each processor, as in System X. In this system, "each process allocator in each processor works independently, examines the priority of different process-demanding tasks and is able to initiate interrupts. (A common data area in the memory is, however, allotted to such things as the map of suspended processes.)" [5c]

6.3.4. The novelty of distribution of some control functions in System X probably explains why the feature was dealt with so circumspectly in the descriptions of the system given in the collection of POEEJ articles in 1981 [9]. No doubt it was a matter of waiting until the ordeal of the system's first few years of service was over before daring to claim its merits.

To anyone delving into the collection of POEEJ articles, therefore the manifestation of the decentralized control principle is not immediately evident at first reading. Indeed, it will be found compressed into only a few cryptic lines on page 92 of [5c]:

"The PU (processor utility) architecture provides for multiprocessing with n + m CPUs having access to p + q store blocks: the values of m and q to be decided by the security needs, and the values of n and p by the processing capacity required."

7. On the terminology used

7.1. English has now become the lingua franca of all switching experts. British texts, which personify perfect orthodoxy and are very careful about the new coinages which abound in the New World, therefore serve as reference models for international publications such as those of the International Telecommunication Union (ITU).

7.2. The terminology introduced in respect of System X, however, leaves the reader of the collection of POEEJ articles somewhat frustrated and may sometimes even prove confusing to the poor non-English-speaking layperson [10]. The main difficulty is that the texts constantly serve up three-letter acronyms for this or that of the system's countless components. Even if this practice is everyday fare in many technical descriptions, the academism of these POEEJ texts soon starts to resemble a coded language of the sort so dear to the military [11].

8. Major features of System X

Let us now mention just two of the main features of System X while referring readers who wish to know more about the system to the POEEJ articles themselves [5].

[9] So great was the discretion displayed that there was no mention of the source or any description of the characteristics of the microprocessors, although these were widely used in the control system as essential intermediaries between the tasks/messages of the software and the hardware elements on which they operated. Only one sentence: "Commercially available microprocessors are treated as circuit components and are not described" [6, p. 232] – a sample of administrative modesty if ever there was one.

[10] As an example for this difficult reading, this one: each multiprocessor (or microprocessor ?) is quoted as a centralized processing unit ("CPU"). While this is admittedly a common enough term in computer jargon, it is rather disconcertingly used here to denote an application which is precisely the opposite of centralization.

[11] However, it is refreshing to discover amid what seems to be so much esoteric jargon the expressive and evocative term "tram", a new neologism if ever there was one [5e, p. 103]. Straight from the imagination of an inventive engineer, this is not for once an acronym but a term derived from or related to the word "omnibus" or "bus"; it is used to designate one of the functional units of the Message Transmission Subsystem (MTS, another acronym).

8.1. An internal signaling system based on CCITT System No. 7 is used for distributing the task-messages.

For signaling between exchanges other than those in System X, the exchanges are fitted with a subsystem for converting signals received from or to be routed to the various signaling systems used in Britain into System No. 7: decadic, 1VF or MFC. This is known as the signaling interworking subsystem (SIS) and its main unit is called the TS 16 (time slot 16 is the time slot carrying channel-associated signaling for the 30 (speech) channels of a PCM multiplex). Owing to the extraordinary multiplicity of pre-existing national signaling systems used in the British network, the SIS subsystem is as complex as its functions are important (in this connection, see [5d] and [9].

8.2. As in every other system of the same generation, *the use of LSI integrated circuits*, even if initially these were of the sort obtained in the commercial international market and not yet customized (in this connection, see [10]).

9. The digital switching network [11]

9.1. As well as in the articles in the POEEJ collection [5e], the switching network was described in a fundamental article [11] by A.S. Philip of Plessey who had been responsible for the design of this subsystem [12].

9.2. The System X switching network has the conventional architecture of its time: it includes a digital-type "group switch" and, for local exchanges, a "subscriber switch" of which there have been two versions, one analog – using reed-relay matrices – and the other digital.

9.3. The group switch, i.e. the Digital Switch Subsystem (DSS), gained most success through its use in the digital transit exchanges which, up to 1986, has accounted for most of British Telecom's orders for System X.

It is a network:

- for connecting the time-slots of the 30/32 – 64 kbit/s channels of standard 2 Mbit/s PCM multiplexes;
- of a TST type [13];
- of a folded structure;
- fully duplicated to provide continuity of service under fault conditions. (The central space-stage S is implemented as two space-switches ("planes"): one assigned for even number time-slots, the other for odd number time-slots);
- with T-switches operating at a clock rate of 8 MHz and connected to the space-switches by two 4 MHz 512 time-slot highways;
- with three types of arrangement of basic switchblocks interconnecting the inputs and outputs of the T-switches:
  * the basic switchblock, a 32×32 array (offering a traffic capability of 20,000 through-Erlangs);
  * a 64×64 array handling up to 64 T-switches,
  * the largest 96×96 array able to deal with 96 T-switches (100 klines).

9.4. Channel identities for control stores of a basic switchblock are defined by a 12 bit address: 5 bits define one of the PCM multiplexes, 5 bits define one of 32 channels, a busy bit indicates whether a cross-office slot is in use, and there is one parity bit.

The space-switch is composed of nine-wire highways for the parallel transmission of the (8 + 1 parity) bits of a channel.

The bits stored in the buffer of the time-switch are read according to the instruction of a central control unit (CCU). A CCU performs such functions as interrogation for free paths and establishment of such paths when they are found. In view

[12] This is the only article on System X published in the IEEE's "Electronic Switching Digital Systems of the World", edited by A.E. Joel [12]).

[13] However, the "small" exchange switching network uses only standard "T" switches, the intermediate S stages being unnecessary.

of the vital role played by the CCUs, each switchblock of 32 x 32 highway arrays has, to ensure absolute reliability, three CCUs (triplicated) operating in parallel and working on the principle of majority decision on their outputs.

10. The system X control

10.1. A detailed description of the control system is found in the paper read at the 1981 Montreal ISS by M. Ward [7]. It contains block diagrams showing the topology of the respective configurations of the ("centralized processing units" or CPUs) multiprocessors, of the memories and of the input/output units.

10.2. Ward's description refers to two successive versions of the control subsystem (R1PU and, after 1981, R2PU). It also contains an exhaustive analysis of the reasons which led to this substantial modification to the architecture of a control system using multiprocessors. One of the reasons reflected the available increase in memory capacity (and the resulting increase in traffic capability handling, particularly required in view of the prospects of the ISDN service). Indeed, instead of an initial version sending messages asynchronously to the control system buses, a synchronous version was deemed preferable and adopted after 1981, at least for most of the subsystem. "The barrier to performance was the time consumed by the complex protocol, the full handshake which is required in any asynchronous bus system."

Ward's analysis is characteristic of a subject which has been very much on the agenda since the end of the 1970s, namely a problem of store contention of tightly coupled multiprocessors. This is a problem not unlike those that surround the topology of access ports to the numerous work stations of a local area network (LAN) or, in the early 1980s, access to the different stations of an ISDN customer terminal installation. In the case of a public exchange using multiprocessors, however, the problem for the design engineer is the fearsome and complex one of ensuring that up to several million instructions per second are transferred at the proper speed; it is also a matter of coping with a potential traffic flow of several hundreds of thousands of busy hour call attempts (k BHCAs) at large capacity transit exchanges.

10.3. The article we are discussing also offers a good illustration of how the intelligence (data and programs) of the control is shared in the memories of a multiprocessor system.

In the case of System X, there were three levels of memory:

- a limited private memory for each CPU (a 64 kword RAM memory, with words of 44 bits);
- a shared memory between a group of (four) CPUs, with direct access for each of the CPUs to (eight) 64 kword RAM memory modules,
- a very large backing mainframe memory, with indirect access by the CPUs and with most of the data items obtained by using "paging" techniques.

The article explains the role of a CPU by describing it as a "pipe-line machine":

a) with a full virtual memory/memory protection scheme;
b) operating on relatively small data items, on each of which the amount of processing is relatively small;
c) but having to access memory addresses which are items scattered throughout a very large address space; as a result, the need for a considerable amount of "virtual to absolute address" translation, which puts a heavy load on the memory access links.

10.4. The introduction in 1981 of the R2PU control system modified the architecture of System X, which also included substantially improved CPUs.

11. System X implementation

11.1. Britain's leading technical journals and newspapers of the calibre of the Financial Times

devoted major articles to System X throughout the years of its gestation. Not all of them treated the subject with kid gloves: they hit out at both the aura of mystery created around the system itself, and the inevitable ups and downs of a more or less cooperative venture involving four partners in a project which the Press regarded as being entirely [14] financed from the public funds of the BPO.

The long-awaited birth of the prodigy was trumpeted with much ballyhoo, thus drowning much of the unjustified criticism that had been levelled against the system during its development.

11.2. One of the first presentations of System X in working order took place before a huge international audience at the TELECOM Exhibition organized by the ITU in Geneva in the autumn of 1979.

11.3. The first exchange placed in service was a tandem exchange installed at Baynard House in the center of the City of London. It was made by Plessey, was placed in service in September 1980, and switches calls between 40 local exchanges in London. Although its inaugural ceremony was perfect, the characteristics of the system had been known for a couple of years or so and there was really not much more to be said about it. A journalist covering the event for the technical press [13] contented himself with a very brief leader placed in the best British tradition under a pithy title: "System X is alive and yellow". This summarized all his impressions, i.e. that the Baynard House cabinets of the tandem exchange were no longer in the soft grey shades of yesteryears but gleamed with the finest gloss of "off-custard yellow" [15].

The first System X local exchange was placed in service in September 1981 at Woodbridge, with a capacity of 6000 lines. Its subscriber stage was of the analog type with reed-relay matrix concentration.

11.4. An initial specialization of Britain's System X: digital transit centres for a future ISDN service

11.4.1. The years in which System X was finally launched into industrial production were marked by two sets of circumstances:

- a world-wide consensus had been reached on the advantages of time-division/digital switching: the system thus became just one among many of the same sort locked in bitter commercial competition for export markets;
- the technical preoccupations of the 1980s have now turned towards – if not centered on – another objective, namely the implementation of a fully digital ISDN.

11.4.2. British Telecom (BT) is a fervent supporter of the ISDN, particularly since it has lost its monopoly as sole telecommunications operator in the United Kingdom and means to keep or increase its lucrative business clientele which provides it with over half its earnings and is the privileged target for an ISDN service. With the ISDN in mind, a BT "overlay digital network" was to be extended throughout the United Kingdom during the 1980s. Until 1986, System X exchange deployment by BT was destined, by priority, to constitute the nodes of this digital network. With this in mind, a program drawn up in 1980 envisaged the installations of a large number of such digital transit ("trunk") exchanges, to be at the top of the digital network hierarchy.

11.4.3. Accordingly, a first series of System X trunk exchanges using the R2PU control system (see section 10) were launched, starting with the installation of the Birmingham, Coventry, Leeds and London centers in 1985. Fifty five trunk exchanges were in service by the end of 1986; by the end of 1988, their number was up to 70,

[14] At least, until about 1983.

[15] The "yellow" was in fact the standard colour for BT switching equipment at that time. Shortly afterwards BT agreed to adopt the manufacturers' "export" colours of blue and grey, in order to save cost.

forming the completed set of BT's digital trunk nodes.

11.4.4. This first priority of System X for the noble functions of future ISDN centers hides what had initially been one of the targets of the system, namely local exchanges which were considered as a second priority for its British use. (Even if the production of local exchanges are those that could justify huge orders from export markets...)

11.5. As to the local exchanges installed by British Telecommunications during the 1980s, they were to be:

- TXE 4A exchanges (see Chapter V-6, section 8), which came into production at the very moment when the first System X exchange was born;
- followed shortly after – as a result of an international competition born of a British policy of economic liberalism – by AXE exchanges of a non-British design: an outsider, LM Ericsson, managed to slip into the tightly closed circle of Britain's switching industrialists through its local subsidiary "Thorn" (this AXE system, by opposition to System X, was sometimes nicknamed "System Y");
- for a nation-wide inward free calling service known as "digital derived services network", No. 5 ESS of AT&T/Philips (APT);
- and System X local exchanges. If, during the early 1980s, System X production was largely devoted to a BT deployment of "trunk" exchanges, from 1986 there was quite a change in the BT orders, as illustrated by the following figures:

* by year-end 1986, less than one million lines in about 70 local exchanges of System X were in service. The first London local exchange was as late as September 1986.
* by year end 1988, there are over 1500 System X local exchanges in service and others are still being ordered.

Local exchanges were added to the digital trunk network, with priority given to major locations in the main business centres, i.e. the initial poles for introduction of an ISDN service.x

11.6. System X industrial production shared between two partners from 1982

Relations were not always smooth between the three industrial partners called upon to cooperate in the development of System X under BPO guidance, namely GEC, Plessey and STC. Indeed, of the three musketeers who went into battle in 1976, only two (GEC and Plessey) were still in the picture when the system was put into large production in the early 1980s. The book marking the centenary of STC in 1983 describes the somewhat ambiguous position the company had occupied within the System X project:

"In 1975, STC, heavily committed to the development of the TXE 4A, decided to adopt a low profile on work on System X. For their part, GEC and Plessey thought that STC was not totally committed to System X and could always fall back on the competitive product of its parent, the ITT System 12 (the 1240).

That view began to change however when STC received its first major development contract for System X in 1979."[14]

In 1978, STC placed some of its stock on the London finance market in a desire to nationalize a part of its capital, all of which had until then been held by the American conglomerate ITT. The stock prospectus issued at the time mentioned that "while STC is involved in the development of System X, STC will not pursue work specific to competitive systems being developed elsewhere within the ITT group".

In spite of that commitment to System X, in 1982, STC – after receiving assurances from BT of large orders for its TXE 4A local system – purely and simply withdrew from the System X project and its production.

11.7. System X – A Success?

Asking whether System X was a partial success or otherwise is like asking whether a cup is

half-full or half-empty. Anyone wishing to philosophize about the extent to which the initial goals of the project were met might well meditate on the following truths:

1) time spent on the prior discussions of organizational structures is never caught up, whereas time is a crucial factor of any success;
2) the preparation of research in committee is definitely a handicap in industrial ventures;
3) the marketing of one and the same system by two separate industrial groups is never an easy matter;
4) System X is essentially a software system. In the mid-1970s it was difficult to anticipate the financial burden of developing large software system [16)], particularly within a British industry which was for the first time starting to produce SPC exchanges.

Point 4) above, relating to the sky-rocketing price of the software part in the development of a switching system, held good for the entire industry in and around 1980 and in all countries. Depending on the financial capacity of the industrial group producing a system, the project either succeeds, fails, or runs out of steam. Unfortunately, all too many projects throughout the world have actually failed. In the case of the System X project, it can be said that although successful in Great Britain, it has not yet (1988) found the successful overseas market initially considered in the ambitions of its forefathers.

16) A typical example of the ignorance in 1978 of software costs appears in an article in the Financial Times [15], a newspaper well informed about reliable technical and financial opinion: "Software is at the heart of the System X development. It will account for between 30 and 40% of the entire cost of an (System X) exchange." In 1985, many manufacturers estimate after painful experience that software accounts for 75% of the cost of developing a system (see also a similar opinion of the Economic Commission for Europe (ECE)).

12. Alongside System X, a small British public digital exchange

To complete this survey of British telecommunication systems of the 1980s, mention should be made of a system known as UXD5.

This system was developed by BT in its own Research Department to provide a replacement for existing small rural exchanges and to provide cost-effective service to communities of (initially) up to 600 lines. UXD5 is based on a British Telecommunications PABX (the CDSS). It is a fully digital, microprocessor-controlled switch, fully compatible with System X, which was developed for completely unattended operation.

The first UXD5 exchange was put into service in 1979, in a small village in Scotland, Glenkindie, and was then heralded as the UK's first digital exchange. Over 150 UXD5s were in service by mid-1986, manufactured by Plessey. They have had some export sales.

The system was doubled in size and now can serve 1200 lines.

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CHAPTER IX-6

THE SIEMENS EWSD SYSTEM [1,2]

1. What digital system for the Deutsche Bundespost?

1.1. The first effect of the adoption by the Deutsche Bundespost (DBP) in 1979 of a policy of full network digitization was an immediate halt to the development and, later, also production of the EWS space-division switching system (see Chapter V-7).

The DBP' decision had been of a highly trenchant nature and, during the first two years of the 1980s, it was not without some disturbing and painful impact on the German switching industry and its export trade. As a matter of fact, however, the DBP decision to stop the development of analog space-division switching came mainly from the German manufacturing industry itself and, for Siemens, from the will to accelerate the development of its EWSD.

1.2. With hindsight, the DBP's decision may be considered in 1988 to have proved highly beneficial to the German switching industry which was thus able to pull out in time from what turned out to be a dead-end street.

The decision was beneficial because:

- it came just at the time when the necessary components for a fully-digital system, mainly the CODEC devices, became available in large volumes and at an acceptable price.
- the years 1978–1982 witnessed throughout the switching world a genuine blossoming of digital systems resulting from the maturity of digital techniques and offered a wealth of information on the experience available on the operational performance of these systems.
- from a specifically German industry standpoint, it coincided with a radical shift in its technological switching skills, as evidenced by the years Siemens had spent in developing the analog EWS system. Those years covered the transition from the earlier modes characteristic of German switching techniques – perfection in electromechanical refinement [3] – to the new modes now based on the strict discipline of designing SPC software and producing within the firm the LSI and VLSI components needed for digital switching.

1.3. The 1979 DBP decision was also a success on account of the skill with which it was performed, particularly considering that the choice of the German switching system(s) to be used until the beginning of the next millenium was taken in a setting of fierce competition.

The DBP had reached its decision without any of the pussy-footing all too common in such cases. In order to open up competition between

[1] EWSD = Elektronisches Wählsystem Digital, or, in English, = Digital Electronic Switching System.

[2] Although of common parentage and having acronyms which differ only in the suffix letter D, the EWS (see Chapter V-7) and the digital EWSD systems must be regarded as two different systems, each with its own quite distinct individuality.

[3] For the benefit of politicians in many export countries, who might understandably be more familiar with luxurious automobiles than with switching, this perfection in electromechanical techniques had often been compared at that time with the superiority of such German cars as the Mercedes.

Box A

Rules of the game in the open competition for the DBP selection of a digital switching system

1. Conditions for participation

The digital switching system to be selected did not have to be a system designed specially for the DBP. It should be a system developed for the world market and just needing to be tailored to the DBP's requirements. A prerequisite for participation in the presentation process was however that the digital telephone switching system had to be manufactured by bidders mainly in the Federal Republic of Germany. Five companies which were regarded as competent, efficient and reliable were invited to submit tenders. The number ot systems to participate in the presentation procedure was limited to three.

2. Equal trial requirements

Each of the offered systems had to be installed for trials in two pairs of telephone exchanges:

- one corresponding to a trunk exchange version,
- the other, to a local exchange version.

Each of these types of exchanges had a defined capacity that was the same for each bidder. The exchanges had to be made available by a fixed date to be then tested with *simulated load* in order to obtain acceptance. The requirements and duration of these tests were included in a detailed evaluation specification.

Following the preliminary acceptance after the load tests with simulated traffic, a *one-year demonstration period* had still to be satisfied before final technical acceptance of the offerred system.

These different stages ensured that only those systems fully suitable from the technical and operational point of view could reach the price competition. The price competition then was the determining factor in favour of a particular system or in favour of selecting two different systems.

3. Pricing conditions

In the system selection competition, prices had to be quoted for defined new installations and expansion projects scheduled for the first three commissioning years. Detailed quotations for each project were required, individual items having to be numbered and priced separately.

For subsequent orders corresponding to regular purchases, an annual price competition was to be carried out.

industrial switching groups, it established a precise yet drastic program fenced in with extremely stringent rules: the participating groups were required to be German or have industrial connections in the FRG.

The rules that governed the competition launched by the DBP are described in detail in [1] and summarized in Box A.

2. The 1979 EWSD project of Siemens

2.1. In 1979, plans were ready by Siemens for a digital switching system which would be more than a modified version of the analog space-division EWS system. In the presentation given by H. Suckfüll at the Paris 1979 ISS [3] "of a new line of digital switches under development at Siemens", the EWSD architecture was already completely defined in all its details, even if the EWSD acronym did not yet appear explicitly in this text.

The announced Siemens development was for a complete line of digital local and toll exchanges within a unique switching architecture covering an universal range of exchange sizes and adaptations to national environments. In addition to the experience acquired by Siemens in space-division

SPC switching and specially in modular software generation, the system design took advantage of the new LSI chip components and low-cost commercial microcomputers that had recently appeared on the market. Microprocessors offered cheap processing power and their use made it feasible to largely decentralize the system intelligence.

2.2. Even before the EWSD system went into production, its modern and modular-structure characteristics had found acceptance with a number of telephone Administrations [4]. In November 1980 a first EWSD exchange was put into service in South Africa.

2.3. Siemens had to wait however until 1983 before the EWSD acceptance by the DBP confirmed the success of its system:

"After the first digital *trunk* exchanges in the telephone network of the Deutsche Bundespost (DBP) had successfully completed a one-year demonstration period in 1983, a decision was taken in the fall of that year on the system choice. It was for the introduction of the two digital switching systems EWSD (Siemens) and System 12 (Standard Elektric Lorenz) (see Chapter IX-8). The system to be employed for *local* switching was to be selected upon completion of the demonstration period and at the close of tendering for system introduction, early in 1984. These decisions marked the beginning of a new era of telephone switching in the DBP network." [3]

3. The EWSD System Architecture [1b,2,3]

3.1. System Configuration and Control Principle

The EWSD is a digital switching system with a *distributed control*: a central computer control by a "Coordination processor" in conjunction and support by "peripheral processors". The hardware of the EWSD comprises the line/trunk groups (LTGs), the switching network and the

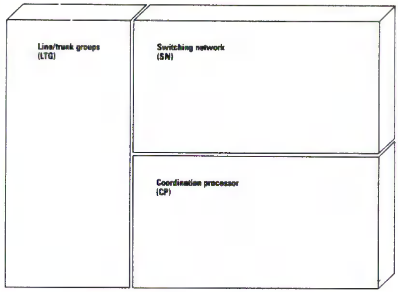

Fig. 1. The three main areas of an EWSD exchange

coordination processor (Figs. 1 and 2) which are interconnected via serial interfaces.

3.2. Line / Trunk Groups

Line/Trunk Groups (LTGs) are the interfaces between the line/trunk network and the digital switching network of the EWSD. To allow for different types of lines and signaling procedures, there are several types of LTGs: LTGs to con-

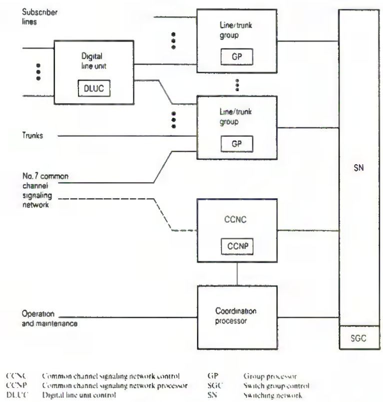

Fig. 2. Structure of the digital electronic switching system EWSD

nect analog subscriber lines, LTGs for two-wire trunks, for four-wire trunks, for digital PCM lines, and, from 1985, digital line units (DLUs) for both analog and digital (ISDN) customer lines.

Each LTG has:

- its own microprocessor, a *peripheral processor*, which has received the name of "group processor" (GP),
- and, for traffic concentration, a time-switching T stage which is called a "Group Switch" (GS).

Within a LTG, its GP, acting as a signal buffer, a processor and a memory unit, processes all the functions that can be executed in the periphery side of the exchange: it handles call-signal processing, carries out routine supervision checks, stores call status information and controls the connecting circuits.

The time-division *group switch* (GS) is of the T-stage type and can accommodate sixteen 2 Mbit/s PCM multiplexes with 32 speech paths each (time-slots). Any two of the 512 (512 = 16x32) time slots, i.e. of the 512 speech paths corresponding to the lines served by a LTG, can be interconnected without any blocking.

Within a LTG, a Link Interface Unit (LIU) connects the Group Switch with two parallel 8 Mbit/s links (128 64-kbit/s-channels) leading to the duplicated switching network. Another function of the LIU is the insertion and extraction of the two 64 kbit/s signaling channels between the Group Processor and the Coordination Processor.

In terms of control, supervision and expendability, an LTG, with its own microprocessor and small switch, is an independent unit. The number of LTGs installed at an exchange depends upon its size and modular expansion is possible at any time.

3.3. The central Switching Network

The central switching network has to provide the paths for the speech connections between LTGs. In addition it switches semi-permanent signaling channels between the controls of the LTGs and the coordination processor.

The structure of the central switching network is a time-space-time (T-S-T) arrangement. What distinguishes the EWSD system from most of the others in its class is that it offers a selection among three types of switching networks and three control complexes depending upon the needs of the exchange installation. The three types of T-S-T distribution switches are designated DE 3, 4, and 5 for 1.9K, 8K, and 80K trunks respectively, the latter engineered for 25,000 Erlangs. The digital speech samples pass through these stages as 8 bits serial. The highways between the distribution switch and the periphery operate 128 time slots at 8 bits serial, at 8.192 Mbits/second.

The switching network is controlled by a microprocessor the main functions of which are:

- to convert the setting data from the coordination processor into hardware-related control signals,
- to perform a check in each path setting,
- to supervise the central functional elements.

The central switching network is duplicated for reasons of system reliability, i.e each connection is switched simultaneously over two identical switching networks so that a second, redundant speech path is immediately available in case of a fault. The quality of a speech path from one LTG via the switching network to another LTG is monitored by measuring the bit error rate.

3.4. The (central) Coordination Processor (CP)

The core of the Coordination Processor is a duplicated switching processor, each containing the following functional elements:

- processing unit (PU)
- memory unit (MU) for programs and data,
- input/output processors (IOP).

The capacity of a switching processor depends on the size of the exchange. In parallel with the three types of EWSD central switching networks, there are three types of Siemens processors designated SP103, SP112, SP113, with busy hour capacities rated at 60k, 220k and 1.2M BHCAs. These designs were based upon the use of 8086 and MC 68020 microprocessors. (For the periphery, the designs were based upon the 8085 microprocessors.)

A message buffer (MB) sequences and distributes the data for the interworking of the coordination processor with the various decentralized processors.

3.5. The EWSD Software

3.5.1. Two processing levels control the functional sequence:
- the Group processor in the LTG performs signaling and the related real-time functions for the terminations served by the LTG,
- the Coordination processor coordinates all functions and also serves as access point for operation and maintenance.

The processing levels of the group processor and the coordination processor communicate with each other in a "process language" which is largely independent of the technical implementation. The coordination processor uses the high level programming language CHILL as standardized by the CCITT.

3.5.2. The EWSD software is developed and supported in accordance with a software engineering production plan using mainly the standardized CCITT SPC languages:
- the "Specification and Description Language (SDL)" as a design aid allowing the developers to design, modify and administer computer-aided SDL diagrams and their graphic symbols;
- the CHILL, CCITT high-level language, to write the source modules of the EWSD software, and for the support software [5];
- the "Man/Machine Language (MML)" to provide maintenance and operation staff with dialogs with the machine, at the command level or in menu-mode forms. (This staff will be located at the exchange or, more generally, in an OMC (Operation and Maintenance Center) to which a cluster of EWSD exchanges are operated and maintained jointly.)

4. The EWSD System Deployment [6]

4.1. The initial EWSD production model was put into service in November 1980 in South Africa. The toll office in the DBP competition was put into service in July 1982 and the first local office in November 1982. The first standard DBP offices were cutover in 1985.

Remote and transportable systems are also available.

4.2. From the beginning of the EWSD development, its full-ISDN capability was a goal. In March 1989, the DBP was able, in what in Germany is considered the world first ISDN network, to interconnect eight big German cities ISDN-served by ESWD exchanges and using traffic routes with Signaling system CCITT No 7.

4.3. In 1979 Siemens established a development facility in Boco Raton, Florida, in the United States. Their objective was to enter the American market to sell to the Bell Operating Companies (BOCs).

Specially after the 1984 AT&T divestiture, Siemens has increased its marketing efforts in the United States, playing with its expertise on ISDN that covers virtually every sector of the ISDN equipment marketplace, from central offices to advanced terminal equipment. For this purpose they developed a trailer with a skeletonized system to demonstrate its ISDN capabilities. Several trial installations have been ordered by BOCs.

4.4. By the end of 1988, EWSD world-wide sales were in 32 countries, to 80 telecommunication agencies, with 8 million lines in service, serving 840 exchanges (and 630 Remote Switch Units) and 6.2 million lines on order for more than 950 exchanges.

The list of the main countries for the EWSD market was at the same date, (lines installed or on order, in numbers $> 300{,}000$):

Germany (Fed. Rep.):	4.1 M ports
South Africa (Rep.):	3.2 M ports
Switzerland:	620 k ports
Pakistan:	600 k ports
Indonesia:	600 k ports
Brazil:	470 k ports
USA:	440 k ports
Belgium:	400 k ports

and Colombia, Argentina and Austria.

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CHAPTER IX-7

THE ITT (NOW ALCATEL) "SYSTEM 12"

Preliminary note

The birth and first steps of ITT's System 12 development sparked great tumult and were accompanied by many hasty and unexpected decisions, most of them taken for financial considerations reflecting the ITT company's industrial policy. Technical considerations also played a part, however, as when questions were raised, at an early time, as to the robustness of design of what some saw as an excessively futuristic system.

Until System 12 came of age and particularly until it reached the point of having many large-capacity exchanges in operation, gallons of ink were passionately lavished on it in both the technical press and to an even greater extent the financial press:

- either praising the system to the skies in conjunction with major advertising campaigns,
- or running it down in a more or less insidious manner. (Industrial competition has not always been waged with kid gloves, particularly in countries where respectable switching markets were opening up.)

All the dust has settled as this book goes to press. However, for the sake of composure befitting an account of the birth and first steps of System 12 (and to make for somewhat lighter reading than usual), let us describe the events as though they occurred in a fairy tale.

1. "As in a fairy tale"

1.1. Once upon a time there was a little prince, the youngest child of a high-born, rich and powerful family. His grandparents and parents had won great renown and their names – Rotary, Pentaconta and Metaconta – had spread to the four corners of the earth. The little prince had from birth been destined to uphold the family name and go through the world from success to success.

He was a much-coddled child. In his cradle he was attended by the wise men of five countries: Belgium, the Federal Republic of Germany, Italy, Spain and the United States of America. As in the best traditions of America's founding fathers, his family had a taste for travel; so, no sooner had his mother given birth to him but he was trundled back and forth across the deep Atlantic.

It is said that he was conceived in 1978 at Stanford in the American State of Connecticut, although the exact time and date are in some doubt because his parents were always to-ing and fro-ing between their many mansions. They had been studying the possibility of having another child for some time. As often happens, however, it was no easy matter for them to fix the precise details of what, to every child, is the especially critical moment of his or her conception [1].

[1] As is often the case with fairy tales there are several versions depending upon the story teller. Another version of its genesis that probably can be documented is that some of the general ideas of a new system architecture germinated at Bell Laboratories near Chicago in 1976, but the management showed little interest in it.

Several individuals then left Bell Laboratories for the newly formed laboratories of ITT in Shelton, Connecticut. These individuals, joined by others then hired there, were assigned to make general exploratory studies of new switching systems. At that time a new system for development was

Once conceived, a first question arose as to the child's future. Should he be given a European or an American upbringing and nationality? The decision eventually went to Europe for impeccable reasons: first there was tradition to consider and, second, most of his family's wealth was there. It was resolved to build him a little palace where he could learn to toddle. The palace was built in Belgium, near Brussels and its aiport, and all the family's European wizards were summoned to counsel on his upbringing and on the gifts with which he should be endowed.

Within his family, however, American doctors and nurses were held in high esteem and were therefore called upon to watch over the little prince during his tenderest infancy. So, once more, he was taken back across the deep Atlantic to spend his first years in the family nursery at Shelton, a smaller town in Connecticut. The best care was lavished upon him. He was to be a little prodigy, highly intelligent, and able to do everything; in particular, he was to become extremely talented at juggling networks, exchanges and so forth in which the wise men of telecommunications take such delight.

The little prince soon cut his baby teeth at Shelton. His constitution had endowed him with naturally strong jaws which enabled him to swallow anything, however hard, chewy or indigestible the food offered him might be.

A little later he was carried back across the deep Atlantic to Europe. The little palace near Brussels was now superbly fitted; he had crowds of servants at his beck and call and as many again were at his entire service at Antwerp, Stuttgart, Madrid and Milan, indeed wherever his family had property. He was a very forward child and as early as August 1982 had taken his first faltering steps in the little Belgian town of Brecht.

From that time onwards his fame was fanfared all over the world and he became famous everywhere. His family's prestige and the winsomeness of the little prince himself promised enormous success. He would surely marry into the greatest families reigning in distant lands and have many, many children.

1.2. So might the fictional history of ITT's System 1240 youth to the mid-1980s be recounted as a tale from the Thousand and One Nights by someone who had been beguiled by all the charms of an Arabian story-teller.

1.3. If a compass is needed to guide the reader through this picturesque account, let us mention the various partners in the development of System 1240:

- in the United States: ITT Technical Headquarters, Stanford (Ct) and the ITT Advanced Technology Center (ATC), Shelton (Ct);
- in Europe:
  - in Belgium, ITT European Headquarters, Brussels; the International Telecommunications Centre (ITC), Brussels and Bell Telephone Manufacturing Co. (BTM), Antwerp;
  - in the Federal Republic of Germany: some experts from Standard Electric Lorenz AG (SEL), Stuttgart,
  - in Italy: FACE Standard S.p.a., Milan,
  - in Spain: ITT Laboratories Spain, Madrid, and SESA (Standard Electrica SA), Madrid
  - and, as with all promising projects, others

furthermost from their mind. But the situation changed rapidly as ITT studies of systems that they had under exploration in their various laboratories worldwide showed the concepts embodied in the Shelton efforts had many attractive attributes. The names of the individuals making the greatest contribution to this system concept appear on the U.S. Patents and the early articles written subsequently as the system moved from exploration to development. For the record their names are J. N. Denenberg, J.M. Cotton, K. Giesken, D. Lawson, etc.

Another element of information on the initiators of the inventive approach which gave rise to the birth of system 1240 is given by Ronayne in [1]: "Prior to the UK decisions on System X there were several contenders (... for the use of microprocessors in switching system development ...). One of these contending systems was the Plessey PP250 processor complex whose development was generated by requirements for military communications systems, ..., as well as public exchange switching. Some leading members of the PP250 development team emigrated to the US and eventually congregated in the ITT Advanced Technology Centre in Connecticut".

wanting a piece of the "action", such as STT Austria, SEP Finland, STK Norway (Also note, in this initial stage of basic design, the quasi-absence of SEL in W. Germany, who in a later stage of development was considered to have been most responsible for the ultimate success of the system [2].)

2. The place of System 1240 in the chronology of ITT systems

2.1. The traditional chronology of ITT systems

The various systems of the ITT Group are characterized within a chronological series identified by the first or last two figures of their "vintage". The series began with the figure 7 for the various versions of ROTARY systems produced from the 1920s until about 1955, and had reached 10 and 11 for the different versions of the ITT space-division system which became better known under the generic name of Metaconta.

The Group's last-borns therefore came to be assigned the number 12 or, to be more precise and concerning the successful child, under the registered number 1240. Before System 1240, three other developments were also labelled with the prefix 12.

2.2. ITT System 1210 [3]

ITT System 1210 belongs to the same chronological series and predated the 1240 by only a few years. Any confusion between these two systems should be carefully avoided.

System 1210 was produced by ITT due to the fact that, in 1972, ITT took over North Electric's factories at Johnson City (Tennessee) and development laboratory in Delaware (Ohio), after that company had been variously owned. The design of system 1210 was initiated when North-Electric belonged to the Swedish LM Ericsson Group [2)] before falling within a short space of time to United Telcom, another technological conglomerate.

System 1210, once known as the "Digital Switching System" or DSS, is indeed a digital system and was produced in two versions: local exchanges (DSS1 with a maximum nominal capacity of 26 klines) and trunk exchanges (DSS3 with a nominal capacity of up to 32 ktrunks); in addition, a third version was a combined local/trunk exchange.

With a TST-type switching network as its group switch, handling twenty-four 1544-kbits/s PCM multiplexes, System 1210 is essentially intended for the North American market, particularly the independent companies, i.e. those outside the Bell System [3)]. Several offices were also installed in Taiwan, the Philipines, and Caribbean islands.

The 1210 system was first placed in service in 1978 at Emlenton, Pennsylvania, as a prototype exchange and was mainly produced under ITT auspices in the early 1980s. By year-end 1986 it accounted for more than one million installed lines in about 200 offices.

2.3. ITT Systems 1220 and 1230

Between the numbers 1210 and 1240 in ITT's chronological series, Systems 1220 (transit application) and 1230 (local application) were also registered as ITT models [4]. These were researched and developed by BTM (Antwerp) and SEL (Stuttgart), respectively, but were never placed in production.

System 1220 had an architecture derived from the Metaconta transit exchanges but transposed with a digital switching network. It was a follow-up of the PCM-C development mentioned in

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[2)] concerning the various takeovers of North Electric and its ownership by LM Ericsson between 1951 and the early 1970s, see Chapter VIII-7, section 8.

[3)] although one central office was installed in (and later removed from) an office of the New York (Bell) Telephone Co.

Chapter VIII-3, section 7, and it was nearly a twin brother of the initial version of the MT20 system marketed independently from the ITT group after the takeover in 1976 of its French subsidiary LMT by the French company "Thomson" (and, later, CIT-Alcatel).

2.4. Starting about 1982, system 1240 that we shall now describe, was referred to as "System 12".

3. Basis for the design principles of System 1240 [5]

3.1. After two years of advanced development work, in May 1980, ITT was granted a major U.S. patent [6] with 22 claims in digital switching network and control, which formed the basis of what became System 1240.

In its studies in the late 1970s, ITT had recognized that the 1980s would herald the start of rapid change in the world's telecommunication network, a change driven by increasing subscriber demands for more sophisticated services, by rapid advances in VLSI technology and the appearance of relatively low-cost microprocessors.

The trend to the integration of voice and various data services in a single digital telecommunication network, i.e. the ISDN concept, was already duly realized by the System 1240 designers. Its architecture had to be able to handle the complex user-interfaces and greatly increased call handling capacity required in such an environment.

Thus one of the primary objectives when developing System 1240 was to design an architecture that would be economical over wide range of sizes and future safe, i.e. which would allow evolution in technology and services without fundamental architectural changes.

3.2. At the same time, effective use had to be made of VLSI technology by adopting a highly uniform and repetitive architecture so that advantage could be taken of high volume of a very limited number of main VLSI components obtained in a mass-production process [7].

The result was the System 1240 distributed control architecture with an extensive modularity, standard interfaces and intelligent digital switching network. This architecture was qualified as being essentially "a software-based architecture".

3.3. Implementation of distributed (peripheral and network) control involved a number of imaginative new engineering concepts. The most important were:

- a switching network which can be controlled from its end points without requiring a central control to establish and maintain paths, and
- a software structure which allows a number of autonomous microprocessors to cooperate in handling of the exchange functions.

This software structure required that each microprocessor be able to establish paths through the switching network both for terminal-to-terminal connections and for passing control information to other microprocessors. No separate data communication path is provided for the microprocessors: they communicate with each other over the same paths that are used for speech.

4. A difficult adolescence

4.1. System 1240 (we shall say from now System 12) was one of the last-born of all the systems covered and described in this book.

The adolescence of a switching system is, like that of any child, always a difficult time as every parent knows. That was particularly the case for System 12.

As with many switching systems employing new principles, it usually takes longer and costs more than expected to make it into a commercial product. System 12 was no exception. There had been excellent marketing and sales activities for the system, lauding its new concepts. Sales of System 12 had grown but the shipments and successful cut-overs were lagging. The implementation of the new design concepts of System 12 were raising problems, mostly software or teletraffic problems. Gradually all these problems were solved but the adjustment period was long and costly.

The adaptation of a switching system to all the facilities and features required in the telephone service of a country was also a costly process; that was specially the case for a System 12 adaptation to the North-American environment where more than one thousand specific telephone features and service requirements represent many design challenges. In early 1986, after spending about $200 million on the development of the system for the United States market, a decision was made to withdraw from the further development of System 12 for that market.

The mid-1980s were proving difficult for the switching industry and its finances. However great the capital and reserves of the industrial switching groups, their financial authorities tended always to the view that the pace of progress imposed by research, development and the marketing of their products was starting to reach a dangerous threshold.

That was the case for System 12. It is considered to have been one of the most expensive initial switching development ever undertaken. According to press reports [8], by March 1985 over $1.1 billion (US) had been spent.

As a consequence of all these difficulties, in early 1987, 63% of the ITT assets in the telecommunication equipment manufacturing industry – and including all the rights to System 12 – were sold by ITT to a consortium led by CGE-CIT-Alcatel of France. System 12 is therefore now developed and marketed by "Alcatel NV" along with their E10 switching system.

5. An Analysis of System 1240. Its Attributes [9]

5.1. According to its designers, five attributes characterized and qualified the System 1240. It had to be:

- a fully digital system
- a fully distributed system
- a fail safe system
- a future safe system
- a full range system

5.2. Fully digital

System 12 is fully digital to take full advantage of LSI and VLSI technology. The successful exploitation of this technology required that the system design be based upon circuit elements that may be repeatedly used in large numbers. The principle of distributed control achieved this objective for control functions built from standard commercial microprocessors and VLSI chips.

5.3. Fully distributed

Distributed control is the chief functional characteristic of System 12. The highly modular structure of the system for its distributed control consists of a large set of the so-called "Control Element" devices, which are interconnected by, (and only by), a Digital Switching Network.

The advent of inexpensive microprocessors and their associated low-cost memories made it possible to partition control modularity throughout the system so that there would be no single point in the system where most of the memory resides or the majority of logical functions are executed – in other words, no central control.

Fully distributed control helps make system 12 fail safe (no single central processor controls the entire exchange), future safe (new applications require only new modules), and full range (the system expands smoothly and economically to meet developing needs of the demand in an exchange, and can meet a wide range of markets, from very small to large exchanges).

5.4. Fail Safe

A telecommunications network is fail safe if failure of any one of its functional elements will have little or no effect on the overall system. In System 12 design this was achieved by a number of measures, the most important of which is distributed control over a large number of individual modules. With it, a malfunction in any one module has only a marginal effect on the total system without reducing service below the acceptable limit. For further reliability, many

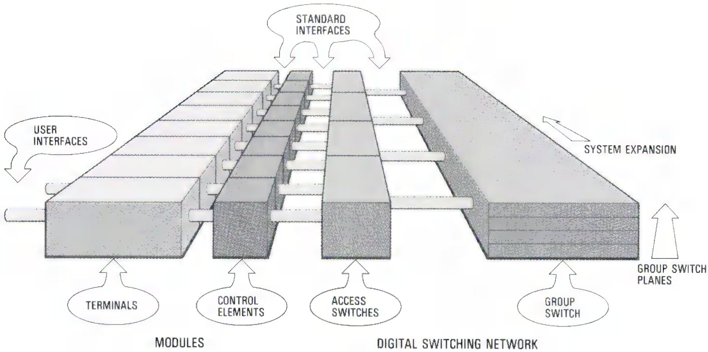

Fig. 1. – System 12 hardware levels

System 12 functional units were either duplicated or triplicated.

Another aspect of the fail safe concept is path reliability. The Digital Switching Network is based on a single custom LSI chip. Each individual chip contains its own logic and memory so that it can carry out three essential tasks; speech and/or data transmission, path selection, and communications between distributed microprocessors. Because each one can do the work of any other, multiple paths can be established through the Digital Switching Network. Failure of any one chip simply means the path is rerouted through another chip.

5.5. Future Safe

In its design, an important aspect of System 12 future safe concept was the exchange's ability to keep abreast of state-of-the-art developments in both hardware and software. Each System 12 hardware module has its own software module with a fixed interface to the rest of the system. Software was structured so that additions do not require extensive retesting of the software already in place.

5.6. Full Range

Like any other important switching system of the 1980s, System 12 was intended to cover the entire range of local, tandem and toll exchange applications, from the smallest remote subscriber unit to the largest local or toll exchange, all using similar same hardware and software modules with the same distributed control architecture. System 12 was also designed to offer "easy-growth" by incremental growth in small steps (60 lines or 30 trunks), and to be applied in various configurations for independent or dependent exchanges.

6. System configuration and control principles [9]

6.1. A modular hardware configuration

The building blocks of the overall architecture of the System (Fig. 1) are:
- Terminal Modules of various types
- Auxiliary Control Elements (ACE)
- the Digital Switching Network (DSN) with its Access Switches and Group Switch

System 12 takes the architecture of a variety of modules, each of which containing its own microprocessor (and the associated software) and connected to a central Digital Switching Network (DSN). This connection allows modules to communicate with each other, in the form of either speech or data. The DSN is the means of this communication.

The control logic for a specific module resides within the module. As a result, System 12 can be modified easily and cost effectively to take advantage of new technology or to add new services.

6.2. *The System 12 Terminal Modules*

Each type of Terminal Modules provides for a different service, for example, the handling of analog lines, digital ISDN lines, analog trunks, digital trunks, etc. (e.g. "clock and tone module").

Each of these modules consists of two parts:

- the "Terminal", designed to serve its specific function,
- the "Control Element", controlling the operation of the "Terminal" and connecting it to the Digital Switching Network (DSN) through standardized message formating.

The Control Elements consist of a small computer (INTEL 8086 microprocessor plus memory) plus a special purpose input/output device ("the terminal interface") to interface with the DSN. Depending on the module, there may be a greater or lesser amount of memory; otherwise all Terminal Control Elements are similar.

6.3 *The control and its distribution*

Control in System 12 is distributed over three levels. Two levels are handled by Terminal Control Element microprocessors (TCEs) contained in specific modules. TCEs control the hardware modules in which they are located and, when necessary, they issue commands to set up paths through the DSN. TCEs are dedicated to a small number of terminals (e.g.: subscriber lines, trunks, computer* peripherals ...). For processing redundancy, line/trunk/RSU interface modules are equipped in pairs: if one fails, the TCE in the

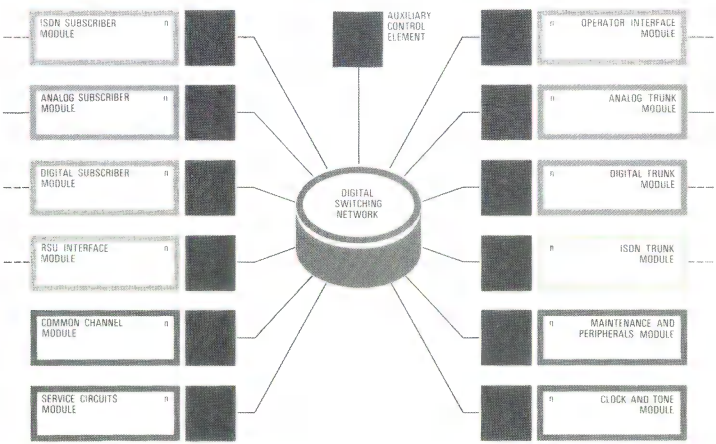

Fig. 2. – The System 12 Digital Switching Network, a "turntable" for all communications (speech or data) between individual terminal modules

paired module takes over immediately and line availability is not affected. This is a form of loadsharing, a popular form of control architecture used in other ITT systems.

The third level of control is handled by Auxiliary Control Elements (ACEs) that perform administration resources management, translations, maintenance checks and similar tasks. ACEs have no dedicated function: each ACE is logically assigned, as needed, to a specific system function by loading it with the appropriate software. ACEs perform operations that are restricted to the processing of data.

All control elements, whether TCEs or ACEs, connect to the Digital Switching Network in the same way.

6.4. The switching network

The Digital Switching Network (DSN) (Fig. 2) is the heart of System 12 and the key to its distributed switching network structure. It not only replaces the conventional network with centralized control, it also replaces the complex bus interconnection systems that in many other systems are required for the centralized control, to communicate with and control each of the individual terminal devices. Hence, the DSN of System 12 is structured to respond to microprocessor commands to set up connections between subscriber or trunk terminals or to other microprocessors, and to transmit any type of speech or data communication.

The switching network incorporates path selection in a step-by-step control that is distributed among the individual stages of the DSN.

The DSN is constructed from one, and only one, functional unit: the Digital Switching Element (DSE). A DSE may be used in a number of modes selected according to the path selection commands applied to the element. A single type of custom LSI chip allows a DSE to behave as an independent switching entity.

Each DSE has 16 switch ports, each bidirectional port corresponding to a 32-channel 2048 kbit/s PCM link. Each channel (incoming or outgoing channel of the 2048 kbit/s link) has a 16-bit word format that may carry speech, data or instructions addressed to a switch port. The DSE performs space-switching between ports and time-switching between channels. Any of the 16 identical ports of DSE may receive messages coming into the Digital Switching Network as well as serving as an exit for messages going out.

The Switch port is the main element of a DSE and has built-in functions for marking, path selection, test, diagnosis and fault isolation. The sixteen identical bidirectional switch ports are mounted on a single printed circuit board.

Although the entire DSN is constructed with the same DSEs, its modular, multistage arrangement is divided into two distinct functional parts:
- the Group Switch.
- the (pairs of) Access Switches, providing access to the Group Switch and performing a concentration function.

(The Access Switches and the Group Switch are composed of exactly the same 16-port DSE. The only difference is in the function they serve.)

7. Software [10,11,12]

7.1. The highly modular structure of the System 12 software is based on a strict partitioning arranged as a number of functional levels. The software functional structure is hierarchical, each level dealing with progressively more detailed aspects of the total exchange requirement. The lowest level is directly associated with the hardware while higher levels carry out particular telephone functions within the exchange.

The software "subsystems" are partitioned into a number of functional software modules with well defined interfaces and which communicate with each other by messages. The software modules are finite message machines (FMM) (see Chapter VII-3, Box B).

7.2. The main programming language of System 12 is on CCITT CHILL which forms the basis of the application programs, e.g. for the FMM software modules. Certain unnecessary features of CHILL, however, were omitted in its use, and it is actually a subset of CHILL which is

employed to simplify coding of CHILL programs.

7.3. A Distributed Operating System, controlling the program flow, is responsible for carrying out real-time processing and managing a database system in which permanent and semi-permanent exchange data are held. The functions carried out by the operating system include: inter-module communication, scheduling and timing of processes, allocation of memory, network communications, software loading and recovery, peripheral device control.

8. Initial deployment of System 12

8.1. By 1987 exchanges of System 12 were already working or being installed in eight countries: Belgium, Denmark, the Federal Republic of Germany, Italy, Mexico, Norway, Turkey and Spain. A few minor isolated prototypes had also been fitted in Chile, China, Israel, Finland, Nepal and South Korea for critical assessment purpose.

It will be noted that the countries with large orders here mentioned and which serve as pointers to the many promising markets expected elsewhere were in 1986 those in which the ITT Group, before the takeover by Alcatel NV of its telecommunication assets, has for long had local industries. Besides the major partners (SEL, BTM, FACE and SESA) mentioned above in section 1.3, ITT also had active industrial subsidiaries:

- in Denmark: SEA (Standard Electrik Aktieselskab)
- in Mexico: INDETEL (Industria de Telecomunicaciones SA)
- in Norway: STK (Standard Telefon og Kabelfabrik A/S)

8.2. Of these eight countries mentioned, the acceptance of the system by the German Bundespost was of particular interest to those countries planning to introduce System 1240 in their national networks.

Indeed, in 1979 the Deutsche Bundespost decided to extend to the main companies of the German Telecommunication industry an invitation for a competitive tender for digital switching systems. Trial pairs for transit and local exchanges had to be installed at the end of 1981 to be cut over in May 1982 with a one-year presentation phase expiring in mid-1983 [13,14]. As a result of meeting the conditions of this tender at the two SEL trial exchanges of Heilbronn and Stuttgart, the Bundespost decided to chose both System 1240 presented by SEL and the EWSD system offered by Siemens for its network's digital switching centers (see Chapter IX-7).

8.3. Before the merger of ITT telecommunication activities into Alcatel NV, SEL was only responsible for development and sales in West Germany; on a world-wide basis, it had not been among the most active of its ITT partner companies, especially in the initial design of the 1240 system. However, after the Alcatel NV merger, SEL was given the leading responsibility for the final design and ultimate success of the system [2].

8.4. By the time of the ITT merger into Alcatel NV, the sales forces of ITT throughout the world had always been very successful, even more than the early and preliminary system performances. By 1987, while only about 1.5M lines had been delivered, sales amounted to more than 12.5M "equivalent lines on order" in 20 countries. By 1988, the corresponding figures for deliveries and awards orders were respectively 4.5 and 20 million.

System 12 technology transfer agreements had also been reached in 7 countries in 1986 [15].

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CHAPTER IX-8

DIGITAL SYSTEMS OF JAPAN D60/D70, NEAX61, FETEX150, HDX10, KB270, XE30

1. The need for digital communication in Japan [1]

1.1. In Chapter VIII-3 the early experiments and test beds for time-division switching in Japan, the DEX-T1, DDX, KOH 40A were described. These early test beds and experiments at NTT-Electrical Communication Laboratories (ECL) were to explore the combining digital switching and transmission.

In the 1970s, various digital transmission systems, such as the DC-400 multiplex long haul system, were developed in Japan. LSI technology also progressed rapidly. Under these circumstance, NTT planned to pursue network digitalization strategy in the following evolutionary stages:

(1) digitalization of the transit network,
(2) digitalization of the local networks, and
(3) digitalization down to customer stations.

1.2. By 1981 there were more than 500 modern SPC space-division offices in service in Japan. ISDN was becoming an important consideration for the future of combined voice and data transmission. In Japan this was particularly vital since Japanese language and its writing required different considerations for the future needs in digital telecommunications. One important service difference was the emphasis on digital facsimile service. Therefore plans for an "Information Network Services" (INS) trial was made with a target date of 1984 [2,3].

2. The D60/D70 digital time-division systems for NTT

2.1. In the meantime developments [4] were started on both a toll (DTS1 [5] and DTS11 [6]) and a local (DTS2) digital time-division switching systems for domestic use. (Note the numbers assigned to these systems, numbers reflecting the relative importance of toll (transit) and local, much the same as the French and American experience). These developments were carried out by ECL with the usual development contracts with the four suppliers of central office equipment. An experimental DTS1 was installed in the Karagasaki, Tokyo, office in January 1981. A DTS2 testbed was installed in ECL in 1980.

As deployment neared the development, codes were changed by NTT and are now:

- *D60 system*, for the large *toll (transit) system* developed to execute stage (1), and
- *D70 system*, for the *local and medium-size-transit system* for stages (2) and (3). D70 system for stage (3) has digital subscriber line interface functions in addition to stage (2) functions.

2.2. Both designed by ECL (NTT) in the early 1980s, D60 and D70 are two brother systems, with the same features in a common architecture, their main difference being the size of their speech path switching network. A fundamental philosophy in their common design was to obtain all the flexibility needed for future applications. These were to cover not only telephone switching but also various kinds of information transmission:

data, text (especially facsimile), pictures, and even unforeseable applications. For this purpose a distributed multi-processor architecture was employed for future processor capability expansion and function enrichment. The two systems have in their software a lot of common programs and their architecture made it possible to standardize software systems for local and toll applications, and from small to super-large offices [2].

In their switching network, the D60 and D70 systems provide 512 time slots of 8 bits parallel giving an internal clock rate of 30 MHz. The capacity of the central switching network, provided in $n+1$ redundancy, is up to 20,000 Erlangs. Also, for growth, a junctor switching stage can be inserted. The control of the switching network was taken from the D20 system. In the same manner, the central control of the two systems was taken from the improved D20 processor. Maximum BHCA rate is 660,000 for the D60, and 177,000 for the D70 in a combined local/toll environment.

D60 and D70 software is divided into functional modules with clearly defined interfaces between modules. Software for D60 and D70 was designed on the basis of the D100B, the latest version of the D10 system. Consistent with the NTT policy adopted in 1978 for its D100B, the programming language used for D60 and D70 is the CCITT-CHILL language.

For the local system (D70) two different concentrators exist: a time-division concentrator for high traffic offices, and a space-division concentrator for low traffic offfices. There are eight line circuits per printed wiring board.

2.3. The D60 system was developed first and put into commercial service at the Ohtemachi Office in downtown Tokyo in late 1982. Digital transmission facilities were growing and the D60 provided the needed synergistic interface with these systems.

The D70 is a system for local networks. There was less urgency to place this type of office into service. Since the INS (Information Network System) digital network plans were not exactly compatible with the emerging ISDN standards, replanning of NTT's network strategy was needed. The first D70, called D70(A), was put into service at Daido office in Nagoya in November of 1983 in an analog environment. Another D70 of later design, the D70(D), was placed into service in the Mitaka office in the suburbs of Tokyo in September 1984 using digital facilities to form a link in the chain of INS model system trial [3].

2.4. The D60/D70 systems were developed for use in NTT network under the direction of K. Gotoh of NTT with cooperation of the Nippon Electric Company Ltd., Fujitsu Ltd., Hitachi Ltd. and Oki Electric Industry Company Ltd, and manufactured by these companies ([7–9] for D70 and [10] for D60).

2.5. As of March 1989, there were 745 D70 offices installed serving 13 million lines. There were 130 D60 toll offfices serving about 220K trunks.

Remote controlled switches with a 300 Erlang capacity for a maximum of 6,000 lines are available. Also available are KS1 emergency transportable exchanges in several containers, based upon the D70(D) architecture and technology, and manufactured by Hitachi.

2.6. Kokusai Denshin Denwa Co. Ltd. (KDD), the international telecommunication carrier of Japan, has over the years worked with the manufacturers, particularly with Nippon Electric Company, in the development of systems using the latest technology and meeting the unique and very specific requirements for the Japanese international gateways [11]. Portions of these KDD systems were generally derived from other systems in production. For digital switching KDD developed the XE30 digital time-division system [12]. The first installation, in an XE30A version, was in Tokyo, in service in 1987. Another version of the system, the XE30B, provides in 1989 the Tokyo and Osaka international gateways with CCITT signaling system No. 7 and other improved facilities.

3. Export digital time-division systems by Japanese manufacturers [1)] [1]

As in the case for space-division electronic switching systems, the four Japanese manufacturers of switching equipment also developed digital exchanges for their own export business strategies as follows:

- The NEAX-61 System of Nippon Electric Company Ltd., developed under the direction of N. Shimasaki, first put into service in Manteca, California, U.S.A. in 1979 [13,14].
- The FETEX-150 System of Fujitsu Ltd., developed under the direction of R. Sugioka, first put into service in Singapore in 1981 [15].
- The HDX-10 System of Hitachi Ltd., developed under the direction of Y. Mijioka, first put into service in Sri Lanka also in 1981 [16].
- A KB270 System (small capacity office) of Oki Ltd., another NTT'supplier of the domestic D70 system [17].

The following section presents a general introduction to the architecture and features of the Japanese systems, followed by section 5 dealing with the specifics on the development and deployment of the Japanese export systems.

4. Features of the Japanese switching systems [1]

Key technologies of digital switching systems developed in Japan are described broadly below. Divided into line concentration, switching network, control, and software, this description also covers what are the specific aspects of the different – domestic and export – systems.

4.1. As is generally known, *line concentrating equipment* can be categorized into time-division and space-division types. The former is relatively more expensive when the traffic rate of subscribers is low. However, system architecture is simple, and more readily applicable to the support of digital subscriber line interfaces. The advance of BORSCHT LSI technology has tended to decrease the cost problem for time-division line concentration.

Study of high-voltage-protection and analog LSI technology application to BORSCHT circuits started at an early stage in D70 development. A fully electronic subscriber line interface circuit consisting of four chips was developed for the D70 system and put into commercial service from 1983.

The NEAX-61 adopted four-wired space-division line concentration equipment with low-voltage CMOS switches, per-line BORSCHT circuits and shared Codecs.

The FETEX-150, put into service two years later, adopted a time-division line concentration methodology. The subscriber line interface circuits (SLICs) for these systems were implemented by using some magnetic circuits, importance being attached to low cost from the beginning stage of the introduction.

4.2. A general feature of the *switching networks* of these Japanese systems is the use of a "TSnT" type of switching (where n is the number of space switch stages) and, for the time-division switch, of a number of multiplexed time slots relatively larger than in other countries. The D70, FETEX-150 and KB270 employ 1024-multiplexed TST network, while the NEAX-61 and HDX-10 adopted 512-multiplexed TSST network.

4.3. The *control subsystems* are constructed by means of a multiprocessor architecture combining function-sharing and load-sharing approaches. Though detailed structures are different within each system, common features are that the processing capacity can be modulated depending upon the office size by introducing a different number of processors. Processors adopted in the D70 and FETEX-150 make use of a 32 bit architecture, while the NEAX-61 and HDX-10 are 16 bit systems. VLSI technologies are used in processors of D70 system.

1) In addition to the discussions of the NEAX61 and FETEX system developments in this Chapter, the reader is also directed to Chapter VIII-7 (section 9.1) for events relative to the specific applications of these systems in the United States.

4.4. In addition to these technologies above, there are *architectural features*. For example, the D70 system used in the Japanese network has three major features:

(1) a function-sharing architecture. In order to assure flexibility in regard to future introduction of new services and technical improvements, the switching system is divided into five subsystems: line concentrator, distribution network, exchange terminal, control, and operating and maintenance subsystems;
(2) a modular software architecture involving use of the CCITT-CHILL language;
(3) compactness and high reliability through use of LSIs.

5. Japanese export systems' developments and deployment

5.1. The NEAX61 of NEC

As of early 1987 there were more than 5 million lines of NEAX61 equipment in service in 37 countries, with more than 10 million additional lines on order. The system has undergone an extensive evolution with the development of versions for remote, small office, operator, gateway, and transit applications for a total of more than 1150 offices. Besides Japan, manufacturing is carried out in the United States, Argentina and Malaysia. Other countries with large deployment of the system are Brazil, China (People's Republic of), New Zealand, Syria, Thailand and Venezuela.

The NEAX61K was an improved ("K = kai") version with particular emphasis on the equipment design. For large installations multiprocessing is employed. The latest version (1987) is the NEAX61E using 32 bit custom multiprocessor chips. These form the basis for a multi-processor system with an expected capacity of one million BHCAs. Demonstrations of high speed packet switching modules with a throughput of 128 Mbit/s have been made with the NEAX61E. A proposed application of the NEAX61E is as an adjunct to space-division electronic switching systems to provide ISDN (see Chapter VIII-7, section 9.1)).

A small 2,000 line ISDN switch, the NEAX61VS, with use of CCITT signaling system No 7 is on trial. Mention is also to be made here of the NEAX61R remote switch and the NEAX61INS international gateway switch.

5.2. The FETEX150 of Fujitsu

Like the AXE10 system (see Chapter V-10), the Fujitsu switch family evolved from a space-division system, the FETEX100, to a time-division version, the FETEX150. Besides the basic local and toll FETEX150 switches, the system provides also remote concentration switches, a transportable version known as the FETEX200, and an international gateway version.

The FETEX150 uses pairs of 32 bit central processors with a maximum of eight pairs. Its central switching network has a 24,000 Erlang capability with a dual-standard digital switching modules that can be automatically switched to μ-law or A-law coding standards. Maximum line terminations is 240,000, in the higher bracket range of other swiches of this generation. The estimate traffic capacity is 700,000 BHCAs.

FETEX150 software is written in FSL, a Fujitsu proprietary language.

The principal thrust of the present FETEX150 developments is for the ISDN oriented services [18]. With Fujitsu's reentry in the United States market for these applications, FETEX development has been extended to broadband ISDN.

Nearly 600 offices of the FETEX family were reported on order or in service at the end of 1988. In addition to Singapore, systems have been installed or ordered in 11 other countries including China (People's Republic of), Columbia, Hong Kong, and Jordan.

5.3. The HDX10 of Hitachi

The HDX10 was the first system to use the high-energy semi-conductor crosspoint for line concentration ahead of the shared BORSCHT circuits. As a result, for applications where the traffic was light, Hitachi advertised the highest

capacity switch of its day, viz. 240,000 lines and 750,000 BHCAs. There are a maximum of forty load-sharing 16-bit CPUs. Like the D60/D70, the control process is of the hierarchical type with the hardware control separated from the call processing. Sales have been reported in eight countries.

6. ISDN technology in Japanese systems

6.1. Having achieved full automation of the Japanese telephone network, NTT is now constructing the infrastructure for the Information Network System (INS) which combines communications and information processing. The INS concepts were originally expounded by Kitahara in 1978 and were adopted as a major NTT strategy [19].

A Model System for this INS was put into service in Mitaka area of western Tokyo in late 1984 [20]. Objectives were to confirm feasibilities for new telecommunication services offered to prospective users, and to survey just how users would utilize these services. Not only 64 Kbit/s services but also high-speed and broad band services were being offered via this Model System. 64 Kbit/s digital services were realized by adding digital subscriber interface functions to the D70 system.

The following two types of user-network interface were used:

(1) Channel associated type: with an interface structure $(B1 + D1) + (B2 + D2)$, where $B1 = 64$ Kbit/s, $B2 = 16$ Kbit/s, and $D1 = D2 = 4$ Kbit/s;

(2) Common channel type: with an interface structure $2B + D$, where $B = 64$ Kbit/s and $D = 16$ Kbit/s.

The channel associated type was designed for comparatively simple terminals expected to be used at early stages of the INS project. The common channel type is the one in accordance with CCITT recommendations ("I-Series"). These two interfaces had different functions with each other in the ("1-" and "2-") lower ISDN layers, while the layer-3 functions were similar, especially in the way of controlling telephone and non-telephone calls integratedly. Only the channel associated type had been tried in the INS Model System, since CCITT recommendations were not available at that time. A variety of tests were continued until March 1987 to examine both the technical and sociological aspects of the INS Model System

6.2. In the meantime, the study on the ISDN interfaces had been actively pursued in CCITT. NTT largely contributed to this study in taking advantage of the experience obtained with its INS Model System. After the main parts of the CCITT interface specifications were made available in 1986, a full set of these recommendations were implemented in Japan at the end of 1988. NTT has committed itself to introduce the ISDN commercial services in using the user-network interfaces defined in the CCITT I-series Recommendations. The basic "I-interface" for circuit-switched service was put into commercial service in April 1988. The H channel circuit-switched service through primary rate interface was put into service in 1989.

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CHAPTER IX-9

ITALY AND ITALIAN SWITCHING SYTEMS

1. Italy, a country of antiquities, even for its telecommunication operating structures

1.1. To a non-Italian, learning about and describing the organizational structures of Italy's telecommunications without too many errors is not an easy matter, whether we are talking about the structures governing network operations or those of the industrial corporations producing equipment for the country's networks.

The present tangle of nominally separate though by and large related companies is explained by reasons which often go back more than 60 years, i.e. antiquity in terms of telephone history. In it, the archaeological historian will discover traces of all the major events which have marked Italy's political developments over the past half-century. The art lover will be inclined to compare the scene to the beautiful Byzantine mosaics so treasured in the North of the country. Lastly, the sociologist will unhesitatingly see in this strange mix – in which the most absolute Roman legalism with its tendency to create top-heavy bureaucracies is blended with great pragmatism for circumventing artificial constraints likely to impede vigourous development – a triumph of Italian genius.

1.2. Let us start with the easiest part if we can so describe it, i.e. the operational structures of the telephone service in Italy [1].

In 1925, Mussolini's new regime in Italy had geographically divided the operation of the country's local networks into five large regional areas and had granted the operation concession of their different networks to independent private telephone companies [1], each under the control of this or that foreign telephone equipment manufacturer.

That same year the operation of the Italian long-distance network was also offered by tender to foreign companies to attract capital and technology. Unlike what happened in the case of local and regional network operations, none of the companies notified evinced any interest in accepting the offer. This failure in 1925 of Italy's plans for long-distance operation offers the historian of telecommunications the most striking demonstration possible of the scant interest shown in long distance telephony at the time. Times change and prospects with them!.. As a result of this 1925 failure to place the long-distance service into the hands of a private company, the latter remained and is still now under a State administration, the "Azienda di Stato per i Servizi Telefonici" (= ASST). This Administration operates long-distance telephone relations between major Italian districts, as well as to and from countries of Europe and North Africa. Another company, "Italcable", operates all intercontinental telecommunication services (excluding North Africa). A third company, "Telespazio", operates satellite services, providing intercontinental telephone circuits to Italcable.

1.3. In 1964, SIP [2], initially the operating company of the Piedmont area around Turin (in Northern Italy), amalgamated the four other regional companies originally set up in 1925, companies such as the SET in Southern Italy. However, since each one of the regional companies had for decades been under the control of sub-

[1] See in Volume I, p. 253, the names of these five companies and the areas covered by each of them.

[2] SIP = Societé Italiana per l'Esercizio delle Telecomunicazioni spa., in Turin.

sidiaries in Italy of multinational equipment manufacturers, each part of Italy had its traditional and exclusive provider of switching equipment. They were:

- the ITT subsidiary FACE [3] in the northern part of the country (Bologna area),
- the FATME [4] – a subsidiary of LM Ericsson – for the SET company in Naples, operating in the southern part,
- an Italian subsidiary of the American GTE in Lombardy (Milan area) [5]
- and finally the Siemens Societa Anonima di Telecomunicazioni (SST) also based in nearby Milan.

1.4. ASST is a Department of the Ministry of Posts and Telecommunications

SIP, Italcable and Telespazio are owned by STET [6], the national holding of State telecommunication enterprises, which in turn is held in its majority by IRI, a special public body created by the Government for reconstruction of Italian industry after the World War.

1.5. Despite its complexity – the most complex one in Europe –, this structure was fairly successful in providing telephone services until the mid-1970s: the Italian telephone network was one of the first in the world to be entirely automated and the telephone density in Italy was among the highest in Europe.

But, from the first oil shock onwards, the whole STET group ran into huge dificulties.. Until then, it had been used to conduct its development strategy in a completely independent position, without even asking for telephone tariff increases until 1974. Lacking political influence at that time, STET did not receive financial support from the Italian State to enter in the huge and costly developments needed for modernizing the Italian telephone network and for initiating autonomous Italian research for digital switching: politicians did not see any interest in these matters. [2]

To remedy the situation, many plans were made in the early- and mid-1980s to restructure the organization of the Italian operating entities and to obtain a concentration of efforts of their equipment manufacturing companies. Sections 3 and 4 below describe the results obtained by these plans until 1989.

2. An early Italian start in electronic switching. Italian Siemens becomes "ITALTEL"

The foremost producer of electronic switching equipment in Italy today is Italtel. In 1921 Siemens of Germany established in Milan a subsidiary: Siemens Societa Anonima di Telecomunicazioni spa, to make or import telecommunications equipment. Production in Italy started in 1927. After World War II, in 1960 the company resumed its activities under the new name of "Societa Italiana di Telecomunicazioni Siemens spa" (SIT-S).

Using technology imported from West Germany, SIT-S developed an Italian version "SEAM" (its Italian acronym, also called ESM III according to its German acronym) of the Siemens space-division prototype systems of the ESM series (see Chapter V-7, section 8). A trial exchange in Rome was put into service in June 1965 [3]. The system used ESK relay matrices and a wired-logic electronic control.

In 1980, the name of the SIT-S company was changed to Italtel. The company then went under the control of the STET and became the principal supplier of network systems for SIP, the Italian telephone operating company and the purchaser of nearly 95% of network equipment in Italy.

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[3] FACE = now Alcatel Face spa, in Milan.

[4] FATME = Fabbrica Apparecchiature Telefoniche e Materiale Elettrico spa, in Rome.

[5] GTE Telecomunicazioni spa, now a member of the Siemens group (stocks held for 65% by Siemens and 35% by GTE International).

[6] CSELT, the research center of the IRI-STET group in the field of telecommunications and electronics, also belongs to the STET holding. Its research results are mainly used by the operating companies (SIP, Italcable and Telespazio) and manufacturing companies (Italtel, Selenia, SGS Microelettronica) of the STET Group.

3. Other switching manufacturers in Italy [4]

3.1. While most of this chapter is devoted to systems developed within Italy by what is now Italtel, one must not forget that by the traditional market allocation described above,

- the ITT (now Alcatel) subsidiary FACE
- the LM Ericsson subsidiary FATME
- and a GTE-T subsidiary (GTE-Telecomunicazioni)

all produced and installed in Italy versions of their flagship electronic switches, 1240, AXE, and EAX (GTD) 3-I and 5-C, respectively, with a share distribution of the Italian market that in 1982 and 1987 was as follows [5]:

	1982	1987
ITT-FACE	17%	14%
LME-FATME	16%	19%
GTE	11%	13%

3.2. In addition to these international marketers there is also TELETTRA, an Italian subsidiary of FIAT, the motor car company, and a newcomer in the Italian switching market (2% in 1982 and 3% in 1987) that had been initially successful in introducing time-division digital transmission systems in Italy (see Chapter VIII-3, section 2).

Under the guidance of Alessandro Bellman in the early 1970's, Telettra developed electronic switching products, notably the space-division system, DST1 [6], and the time-division digital toll system, AFDT1 [7,8]. A number of exchanges of these systems were placed in service in the late 1970s. After the installation of a first node of AFDT1 in Turin in 1976, this system using UFD concentrators provided in March 1983 the first integrated voice and data service in Italy.

Telettra had also commenced in the early 1970s the development of a second generation of time-division digital switches, known as SINTEL [9]. This system was one of the small number of digital switch developments that chose to use S-T-S rather than T-S-T switching networks.

4. How many systems using time-division digital switches for Italy?

With the development of modern time-division digital switching systems in Italy, the Ministry of Post and Telecommunications decreed in March 1982 that there should in the future be only two switching technologies for public switching equipment in Italy, with a concentration of efforts by the Italian manufacturers.

A first progress was made between GTE and Italtel with the latter adopting the GTE-GTD5 line card for the new Italian system to be developed, the UT10/3 (see section 6.3 below).

In keeping with the directive of the Ministry of Posts and Telecommunications, the switching interests of Teleltra (10%), Italtel (60%) and GTE-Telecom (30%) were integrated in 1982 for the purpose of pursuing international markets under the name ITALCOM. A. Bellman then affiliated with Italtel as Executive Director of Electronic Switching.

The Ministry Directorate of course favored an alliance of these partners to be centered around the new system of Italtel then undergoing initial deployment.

By February 1987 Telettra and Italtel had planned to complete a merger under the name TELIT. Each parent company had to receive a 48% of the proposed Telit shares, which represented for Fiat a very large investment. The merger was put off due to a clash between the Fiat management and the Italian Government on the choice of who would be the Director of the proposed Telit joint venture.

In mid-1989, a new orientation was taken and a global alliance was formed between the American AT&T and, on the Italian side, the STET and Italtel. In the concluded agreement, AT&T acquired 20% of Italtel, and STET an identical share of AT&T Network Systems International. The two companies would continue to support their current product lines through their life cycles and would develop common products based on subsystems developed and used by both of them.

No other progress to reduce the number of switching systems to be installed in Italy was subsequentially announced.

5. The first generation of Italian time-division switching systems: "PROTEO I" [10,11,12,13]

5.1. Development of time-division switches by SIT-Siemens was started in the early 1970s. They were called PROTEO, a name derived from the "Protean" variety of configurations that they were intended to have.

The first switch of this first generation – the one called "PROTEO I" - of time-division exchanges was the "CT", a small PAM time-division switch. A 400 lines CT switch was shipped in August 1973 and placed in service in April 1975 in the Settimo exchange in Milan. The initial switch used a 16-bit microprocessor with only 64,000 bytes of memory. Its maximum capacity size was 2000 lines and 180 trunks.

The CT was known as a peripheral exchange. As many as 32 CT exchanges were to be controlled by a remote central control, "CC". Since the CC design was not completed when the CT exchanges were ready for tests, a "DC" ("decentralized control") for a single exchange was developed so that the field trials could proceed. Later it was found that this arrangement was useful in other locations and the DC became part of the "CTA type" ("A" for autonomous) system for independent local exchanges not requiring the services of a CC. The DC contained duplicated 32-bit Hewlett-Packard microprocessors, with a third of these for maintenance.

The production model of this system was known as the CT-2 [9]. It had up to 1M bytes of memory and later (1982) used an improved central processor of Italian CSELT design, known as the MIC20. It also used a MIC16 processor of the same origin for signaling in place of wired logic. The first CT2s were cut over in the Venice, Florence, Messina, and Milan areas in 1979. By 1981, 70 units were on order or in service, representing about 250,000 lines and 65,000 trunks. By May 1983, 100 units were in service. Containerized versions known as CT2-T1 for 1K lines and CT2-T2 for 1.5K lines were also produced.

5.2. Another development started at SIT-Siemens in the early 1970s. There was a need by the Italian long distance carrier ASST for an international gateway exchange, including operator positions to serve the booking and language traffic. The result was a development of a system "Centrale Internazionale Manuale e Automatica", CIMA [14]. This development was continued by Italtel when it superseded SIT-Siemens.

The system was the result of a cooperative development between SIT-Siemens and North Electric in the United States [7)]. The system used a PAM time-division switching network with a maximum of 3200 terminations and a stored program control. The network had 32 highways of 64 time slots and 100 termination each. The CIMA system included both through switching and switching for the operator positions. A maximum of 256 video terminal positions were provided in 8 groups of 32 positions. A version of the system used only for operator traffic was known as "TI-2 (also CIMA-2)" and served only 2000 trunks.

The first CIMA exchange of 1000 trunks (300 alone to France) was cut over in Milan in 1976. Four exchanges were in service in Italy by 1979. A version CIMA3 of the system was sold for export to Oman. For export PROTEO was called PROTEL.

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7) North had considerable experience with PAM technology for military switches and SPC for toll switches in the United States.
There was some expectation at the time of the agreement that developing the system in the United States might make it possible to enter into the American market for smaller local systems, which at the time was already crowded with competitors (see Chapter VIII-6).
It is interesting to note that although this market thrust was dropped in the early 1980s, the idea of invading the US market has remained with the Italians. Mention of introducing this system into the US was revived as part of the joint venture with AT&T in 1988–1989 since AT&T did not have at this time a smaller system to compete with the Northern Telecom DMS10 (see Chapter VIII-7).

5.3. The first generation of PROTEO was not all in PAM technology. It ended with time-division digital development, the TN16 transit exchange and the TN-5 operator system [13], both using the same T-S-T time-division digital switching network.

The TN-16 system used semi-conductor rather than core memories and 34 Mbit/s technology. It has a capacity of 15,000 trunk terminations. The first exchange went into service in Milan in 1980. Thirteen exchanges serving 45,000 trunks were in service by year-end 1983.

The TN-5 system had a capacity of 5000 trunks and 356 operation positions. It also incorporated switched digital echo suppressors and Automatic Message Accounting. The first installation was cut over in June 1980 in Rome, with 64 remote positions in Palermo, 1,000 kilometers away. By the end of 1983 more than 20 other TN-5 exchanges were in service.

6. The second generation of time-division digital switching systems: "PROTEO II", later named "LINEA UT"

6.1. From where do system ideas come? All new systems do not have to originate "in-house".

With the experience of over 50 exchanges behind them and a demonstrated design capability, Italtel set out about 1980 to develop a time-division digital switch for local exchanges. This would have been in keeping with the trends that were in evidence at the ISS in Paris in May 1979.

Additional features and improvements were needed for the CT-2 developments. A small team started exploring the technology, including software, for a system that could cover the size range from approximately 1000 to 14000 lines. It was, however, difficult to find adequate development personnel to start the development of a new time-division digital local system.

The Italtel management was anxious to get closer to the advanced switch technologies and software that were then being applied to similar systems being deployed in the United States. They learned that John Israel of Advanced Business Communication (ABC) Corp. of Dallas, Texas, in the United States had been exploring a new system architecture and was looking to start a venture to develop his system concept. Moreover, in the Dallas area there was a surplus of switching experts, particularly in software.

Taking these factors into account, the STET management, in February 1979 reached an agreement with ABC for a joint initial development effort [15]. The effort was to be divided between Italtel-Milan and ABC-Dallas with some lead designers coming from Italy. Initially the ABC interest was 10% but by the end of 1982 STET bought the design rights to the system from ABC. The emphasis in Dallas was to be on the development of the basic system and software while in Milan the effort was on the central operations control computer.

Great progress was made in two years. The local exchange system specification, using the CCITT "SDL" (Specification and Description language), was written, a 2000 lines field trial was installed and cut over in the Volta exchange in Milan in July 1981, and several system models made for laboratories in Milan and Dallas.

6.2. Linea UT [16]

The second generation time-division switches were all to be digital. The system design had to be based on a modular architecture with the capability to face the fast evolution of the technology in concentrating the variations inside the modules instead of impacting the total system architecture, and to introduce at the most suitable time new features and/or services.

Initially, these switches during study were referred to as PROTEO II. The new local system was planned to be not only modular so that it could grow from a small to medium size local switch but it was also planned as a transit and toll system. The system developed in Milan/Dallas was then called "UT10/3", U for local and T for transit and with the identification, UT10/3, coming from the original objective of 10,000 lines and 3,000 trunks.

Once production began in 1983, plans for this product as well as for a larger system eventually

solidified to become the "Linea UT" (Linea = line), flagship of the Italtel public switching products. At the same time the names of units and modules given below changed from those described in the original literature.

6.3. *The UT10/3 System [16,17]*

As initially described in [16], the UT10/3 system consisted of basic ST ("Stadio Terminale") modules, each with a capacity of 1024 ports and including a duplicated single-stage T switching network (a time slot interchange – TSI – for 256 time slots). A single ST can connect up to 1000 subscriber lines or 256 trunks. The ST modules are fully interconnected by a meshed network of two 2-Mbit/s, 32-channel buses that serve traffic in both directions between modules.

A variety of interface units were provided to match analog and digital facilities for subscriber lines and trunks. A maximum of four interface units formed the ST module. The interface units for subscriber lines used the GTE-T line-cards, each serving 8 analog lines; (for trunks, two trunks per line-card). Zilog Z80 8-bit microprocessors were used with each interface group serving from 8 to 32 lines or trunks. These were then grouped to form interface units presenting 256 terminations on the TSI network.

The control of the system resided in each ST module. One of the objectives was to eliminate a resident central control, although the idea of a remote support central control, as in the CT-2 system, was retained. Initially the control portion of the ST modules, called modular processor (MP), was based upon the use of two of the MIC20 16 bit microprocessors developed for the CT-2 system. Data communication between the ST modules was carried out between the MPs by local buses using CCITT No.7 signaling protocols. The system capacity was advertised as 120,000 BHCAs and 1800 Erlangs.

The central "administration and maintenance" center, called "ES" (Elaboratore di Supporto = Exchange Supervision), was initially a pair of Digital Equipment Company processors.

A remote line multiplexing-concentrating module was developed. Designed initially to cover from the lowest range of capacity up to 240 lines, it was called "MC 240". Its capacity was later increased to 512 lines (a traffic capacity of 100 Erlangs or 6,000 BHCAs). It includes the same basic elements as the ST modules [18], is connected to the host exchange by 32-channel PCM links and dialogs with its UT 10/3 host exchange by means of No.7 signaling. The MC 240 can independently establish calls to emergency numbers when isolated from the host exchange.

The first exchange in the series production of UT10/3 was cut over in 1984. By the end of 1987 there were 1245 exchanges delivered and more than one million lines in service. There were export sales to China, Columbia, Egypt, Ethiopia, Guatemala, Mozambique, the Philippines, Zambia, Zimbabwe as well as a joint venture technology transfer agreement with Yugoslavia.

The capacity of the system was extended to 30,000 lines using a new interface to double the number of STs that could be served without a central switching network.

6.4. *The "UT 100/60" System [19]*

For larger local and transit exchanges, a system called initially the UR100/TN60 and finally "UT 100/60" was developed. It is a system intended to provide service to a maximum of 100,000 lines or 60,000 trunks.

It uses the ST modules of the UT10/3 system and, as for the UT 10/3, remote subscribers can be connected through MC 240 Remote Concentrating Modules. The main difference with the UT10/3 system is the use of a central self-routing switching network (an "interconnection structure") comprising a maximum of three T stages.

This switching network uses a unique LSI chips ECI (Elemento di Conessione Integrato) developed by Italtel in cooperation with CSELT, the STET's research laboratory,. The ECI is similar in function to chips developed by others in the industry to provide two-way buses from eight 32-channel PCM links. Like the 1240 sys-

tem (see Chapter IX-7), the ECI is self directed, i.e. that signals in each time slot indicate the path to be established in the switching network. In this network this function is carried out only once per call. Individual Zilog Z80 microprocessors provide the control for 8 ECIs.

The Linea UT version of the system with the interconnection structure, so called circuit switch, includes a message distribution module (MDM) to provide the data paths when more than 32 ST modules are used in the system. The MDM is connected to the STs by 256 kbits/s data paths and 8 Mbit/s buses are used within the MDM.

For the maximum size exchange configurations, the expectations are for a capacity of 900,000 BHCAs and as many as 25,000 Erlangs. Provisions have been made, almost from the start of development, to provide for ISDN and packet switching.

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CHAPTER IX-10

TIME-DIVISION DIGITAL SYSTEMS OUTSIDE OF NORTH AMERICA, WESTERN EUROPE AND JAPAN

1. Introduction

1.1. In this Part and the preceding Part VIII of the book we described in separate and successive Chapters those time-division digital systems that to date have captured a relatively large share of domestic or world markets.

This Chapter is devoted to mentioning the development of systems designed to fill niches in national administrations or market situations. Nearly all of them were developed for markets outside of North America, Western Europe, and Japan [1]. In many new industrializing countries, a series of initiatives has actually taken place to develop digital switching systems specifically designed for use in their own country. With various motivations and objectives:

- the most important one, a nationalistic policy of their government aiming to promote a telecommunication industry of their own, which would be based not on manufacture under license of a foreign system but on a completely independent and national design [2];
- to obtain systems with only the minimum of facilities required for the customers'needs in the specific environment of a less developed country: features provided in these systems would be only those that the telephone operating agencies of the country consider sensible;
- in some cases, to obtain systems adapted to the specific traffic conditions found in the country, e.g. low telephone density and, consequently, a huge number of calls per subscriber line, i.e. a traffic situation very different from that prevalent in the most developed countries;
- in some cases, to obtain systems that would be relatively inexpensive to develop and, even more, to manufacture. Such systems would include a minimum of components to be imported from the industrialized countries.

1.2. While some of these systems have found some limited success, to date their sales have not been as great as those of the systems covered in the other Chapters of the book. Some of these

[1] However, in Chapter VIII-7, section 9, a similar group of systems for filling up niches in the North American market were also discussed.

[2] Promoting a national (or regional) industry with a technology specifically adapted to the needs of a country (or a set of countries) is, under the best-seller name of "appropriate technology", a subject for many and many publications, conferences and international meetings. Especially under the aegis of the organizations of the United Nations family, such as UNESCO, UNCTAD, ILO and sometimes ITU. For telecommunication industry, see the CCITT "GAS 5" Manuals and, as an article of general policy, a Jipguep article [1] in the ITU Journal. This article lays stress on the following advantages, among others, of a national research on appropriate technology in telecommunications:

"– greater exploitation of local intellectual and inventive capacity;
– transfer of technology;
– reduction of reverse transfer of technology (brain drain);
– increased employment potential;
– foreign exchange earnings."

national developments have been undertaken just to insure that the local engineering talents become familiar with design techniques, particularly software, so that they be prepared for follow on developments, should there be any difficulty in obtaining them from the original licensing manufacturers.

These system designs arise as a result of specific country needs. The remainder of this chapter is so divided by country. In the various design approaches of the systems hereafter described, some common denominator can be observed:

- switching networks with the same T-S-T structure,
- distributed control with large use of (imported) microprocessors,
- very often, clusters of a small number of modular units associated with a host controlling unit, and locally sited in the same central office or acting as remote switching units.

It can also be noted that, once one of these systems has been successful in production, attention is frequently turned to export markets to assist in defraying the development costs.

2. Brazil

It is a Brazilian government policy that telecommunication products used in Brazil be completely manufactured in the country.

Tropico is a family of digital public telephone exchanges, which has been completely specified, designed and developed in Brazil by the Telebras [3] Research and Development Center at Campinas (State of Sao Paulo), with the active cooperation of the Brazilian switching industries and of the Telebras Operating Companies [2]. The Campinas Center, known as CPqD, with 1500 highly specialized professionals, is one of the most important R&D centers existing in Brazil.

Tropico is an abbreviation that stands for "Telebras Digital Telephone System". By 1987, in the Tropico family of digital switching systems, the following had already been put into operation:

- The Tropico C, a subscriber line concentrator for up to 192 lines, under commercial production since September 1983. A Tropico C concentrator is generally connected to its host exchange by a 32-channel PCM link and, when the host exchange is of analog type, a local unit in this exchange provides the demultiplexing of the PCM link channels.
- The Tropico R, a small size local/tandem exchange for up to 4000 subscribers and 800 trunks, (320 Erlangs). The first Tropico R exchange was cut over at the end of 1985. Tropico R comprises two independent switching structures, one for voice and the other for internal signaling: the first is based on circuit switching and the latter on packet switching. Its control is a totally distributed, decentralized control based on the use of several microprocessors. There is also a containerized version of the system. By the middle of 1988 some 200 offices of this type, with a total of 200,000 lines, were in service.
- The Tropico RA [3], a medium size local/tandem exchange for up to 16,000 lines, under development: a prototype was field-tested in 1989 and the first commercial units should be commissioned in early 1990. This system is to be fully distributed with no central control. The terminal modules are for 160 lines and a maximum of 900 modules may be used in an office. The Tropico RA will be provided with signaling modules for both the R2 digital signaling system and the CCS No. 7 signaling system. Its remote local units are a special version of the Tropico C. Several versions of the system, to be provided with switching networks for 2220 and 8880 Erlangs, and eventually for ISDN, are under development.

Two other types of Tropico exchanges are also planned and are under development:

[3] Telebras is a holding company of 29 telecommunication Companies in Brazil, including all telephone companies in charge of the public telephone services in each State of the country and the Embratel Company providing interstate and international communications plus the telex, data and fac-simile services.

- the Tropico L, intended to be a large size local/tandem exchange for up to 80,000 lines;
- the Tropico T, intended to be a large size toll exchange for up to 50,000 trunk circuits.

In 1987, Telebras Operating Companies awarded the Brazilian industries with an order of over 1.2 million lines of the Tropico equipment.

3. Korea (South)

3.1. The deployment of electronic switching in South Korea

A number of South Korean manufacturers have been, and are engaged in supplying switching systems. Beginning in 1962, a succession of Five Year Development Plans raised the number of the Korean main telephone lines from 0.2 millions in 1962 to more than 10 millions in 1987, with 99.5% of subscribers connected to automatic exchanges. In June 1987, all telephones in the country were integrated into a single nationwide automatic telephone switching network.

3.1.1. The first electronic exchanges installed in Korea in 1979 were of the Metaconta system (ITT/BTM, Antwerp) which served as a step-stone for supplying the South Korean network with electronic switching. Since 1979, over a million line units of various electronic switching systems have been added annually to the Korean telephone network.

3.1.2. Through a joint venture with American Telephone & Telegraph (ATT), the telecommunication branch of the Korean Goldstar group was able from the end of 1980 to manufacture a large quantity of local exchange lines of the ATT 1A ESS type (2.3 millions of lines of this type in 1987). Since 1985, Goldstar has also manufactured the large capacity digital toll exchanges of the ATT No. 4 ESS, which were installed in Seoul and in three other main towns to be the transit points at the upper level of the Korean national network.

3.1.3. Otelco (the "Oriental Telecommunication Company") manufactured, in cooperation with LM Ericsson of Sweden, the AXE-10 system which was the first time-division system to have been installed in Korea. The AXE-10 exchanges were installed in 18 small- and medium-sized cities (1987) to serve as the middle level of the exchange hierarchy in the (digital) Korean network.

3.1.4. Samsung (also known under the "SST" acronym) was established in 1977 as a Korean Telecommunications Company by the Korean Government for the manufacturing of electronic switching systems and is also taking an active part in the Korean production of these systems, for both public and private telephony. As a provider of systems for private networks, it supplied the telecommunication systems for the 1988 Seoul Olympic Games.

3.2. After 1982, a national standard switching system for Korea: the TDX system

3.2.1. The name of TDX covers a family of exchange types. The TDX system are intended to become the standard switching system of South Korea [4]. Its development was an ambitious project of advance technology in areas of high-level software, high precision circuit design and development of LSI and VLSI integrated circuits.

The TDX system development results from an initial joint venture between Otelco and LM Ericsson of Sweden. The development of the TDX-1 production system began in September 1982 at the Electronics and Telecommunication Research Institute of Korea (KETRI).

The TDX switching equipment is produced in Korea by four manufacturers, each with the help of an off-shore "advisor" (shown in parenthesis): Otelco (L.M. Ericsson), Daewoo (Northern Telecom), the Lucky-Goldstar group (AT&T and NEC), and Samsung (ITT and Rolm).

3.2.2. The TDX-1 is a small digital switching system suitable for rural areas. For all major

functions, an automatic back-up is provided which gives a quality of high reliability to the exchange.

3.2.3. The TDX-1A [5] (also appearing sometimes in publications under the name of TDX-2) is a digital switching system for small- and medium-sized cities. Designed to increase the capacity of the TDX-1, they are upward compatible.

The TDX-1A control architecture is of the fully distributed type using a single and uniform model of 32-bit microprocessors in a modular configuration with a two-level hierarchy of processors. The software is based upon a modular design technique and uses a message communication scheme between microprocessors according to the principles of a finite state machine. In the TDX software development the SDL and CHILL languages were systematically used.

The TDX-1A switching network is of the T-S-T type. It switches multiplex buses that come from or go to subscriber and trunk modules. A multiplexer converts 32 PCM ports of serial 2 Mbit/s into a byte parallel data stream of 8.192 Mbit/s that feeds to a T switch. A T-switch performs the time slot interchange for the 1024 channels of speech data between these multiplexers/demultiplexers and the S-switch. The S-switch performs the space portion of the switching between 4 pairs of T-switches, providing the overall capacity of 4096 ports.

The maximum capacity of a TDX-1A system exchange is 10,240 subscriber lines or 2,048 trunk circuits, with a traffic capacity of 1600 Erlangs and 100 000 BHCAs. The digital carrier trunk circuit (DCTC) terminates digital 24-channel PCM links (American T1 type) in units of five T1 links (120 trunk circuits). A digital line concentrator (DLC), employing a time-division switch unit with 1024 ports, is used to concentrate the subscriber line traffic.

All facilities for easy maintenance are provided by the TDX 1A through local access and/or a Centralized Operation and Maintenance system, with a standard man-machine interface.

The first delivery of TDX-1 exchanges (24,000 lines installed) took place in August 1985 in four rural areas, after successful field trials in a local exchange in the Daejon area, installed in August 1984. During the two years 1986 and 1987 about 400,000 TDX lines were put into service. An annual installation rate of more than 200,000 lines in urban and rural areas is expected. Otelco is the largest producer with an expected capacity of about 100,000 lines per year.

Export sales of this system to the Philippines have been reported by Daewoo. Each of the four manufacturers has made some variations in the system. The TDX-1G of Goldstar expects a capacity of 22,000 lines, 3800 Erlangs and 220,000 BHCAs. The TDX-1E of Daewoo is 20,000 lines, 3300 Erlangs and 220,000 BHCAs. Otelco has two systems: the TDX-1A for 10,000 lines, 1600 Erlangs and 100,000 BHCAs; the TDX-1B for 20,000 line, 3300 Erlangs and 220,000 BHCAs.

3.2.4. The TDX-10 is a 100,000 lines digital switching system under development, specially designed for large cities; it is scheduled to go into production in 1990.

4. India

4.1. In the 1970s, there were early efforts by the Indian PTT Telecommunications Research Center and the "Indian Telephones Industries" (ITI) (see Box A on ITI history) to develop a stored program control space-division switching system for India [6]. The system used electrically latching minireed contacts and multi-microprocessor controls and was called the SPC-1. One small installation was placed in service in Delhi in 1979 [7].

4.2. A family of Indian digital switching systems is now under development in India [4)]. In the transition from analog to digital underway in the national network of India, special attention

Box A

Indian Telephones Industries (ITI)

Since Independence, the production of telecommunication equipment has been considered an area where the Indian State had to intervene. "The Industrial Policy Resolution of 1948 stated that the future development of the telecommunication industry was to be the exclusive responsibility of the State" [8]. With two other companies (one for the production of telecommunication cables, and the other, of teleprinters), Indian Telephones Industry (ITI) was set up in 1948. Started as a departmental undertaking by the Ministry of Communications, ITI was incorporated as a Company in 1950. ITI is actually a manufacturing company belonging to the State "Department of Telecommunications" (DoT) [5].

In 1989, from the initial one factory at Bengalore producing Strowger switching equipment of the British type, ITI has grown to eleven factories [9]. Among the most important and related to switching, those of:

- Bengalore in Karnataka (Strowger and Crossbar equipment),
- Rae Barelli in Uttar Pradesh, started in 1973 (Strowger and Crossbar equipment),
- Mankapur in Uttar Pradesh, started in 1985–1986, for production of Digital Electronic Switching equipment of Alcatel design (E10B type),
- Palghat in Kerala, also producing Digital Trunk Automatic exchanges of E10B type.

In the mid-1960s, ITI introduced into its Bengalore factory the production of Pentaconta crossbar equipment under a license contract with Bell Telephone Manufacturing Co (BTM) of Antwerp, an affiliate of ITT. Due to certain difficulties experienced owing to maintenance conditions and, above all, because of the very special characteristics of the subscriber traffic offered (very high traffic per subscriber line), a new, specifically Indian version of the Pentaconta was designed by ITI [10] but it took about 15 years before the Indian design superseded in production the initial BTM Pentaconta version.

Even though the studies for this national version of crossbar system took quite a long time, the project had as as secondary effect a large improvement of Indian competence in the field of switching technology [9b]. It was from the nucleus of engineers in the Bengalore R & D department that further developments, first of an Indian prototype of SPC system, later of the digital ILT system, took their roots.

[5] Up to 1985, the State "Post and Telecoms Department" was in charge of the postal and telecommunication services for all the country. In January 1985, the Department of Post was separated from the Department of Telecommunications.

has now been turned to the digitization of rural networks.

[5] These developments are aimed to provide a family of Indian digital switching equipment that would be less expensive than the E10B system manufactured by ITI under a license contract with Alcatel (see Chapter VIII-4, section 4.2) and would incorporate more Indian-manufactured components.

4.3. Indian Telephones Industries (ITI) in Bangalore has designed and is manufacturing, under the name of *ILT-512* (ILT = Integrated Local and Trunk exchange), a specific system to serve the rural networks and provide them with end-to-end digital connectivity and a wealth of new services in addition to voice communication.

In 1987, ILT-512 was the only indigenous Digital Switching System to have received

clearance for introduction into the Indian telephone network from the Governmental authorities of India. Intended for applications in secondary centers and below, it can be configured as Local, Trunk, Tandem or combined exchange. An ILT-512 provides 512 accesses ("ports") to subscriber lines or trunk circuits. The system is modular with respect to maintainability and especially to flexible expansion. Expansion can take place with incremental steps of only 8 subscriber lines or 4 trunk circuits.

The major sub-systems of the ILT-512 are the Individual Processor ("IP") complex (built with 8085 microprocessors) and the Digital Switch ("DS") complex (i.e. the switching network of the exchange), built with one DS for every 256 ports.

An existing expanded version of the ILT-512 is the ILT-2048 offering a capacity of up to 2048 ports. It is virtually a cluster of four ILT-512 systems put together with a coordinating processor.

The first ILT-512 exchange was put into service in the Kerala State in July 1984; in 1987, 30 exchanges of this type were in service. The first commissioning of an ILT-2048 exchange took place in May 1986 at Bengalore.

4.4. Mention is also to be made of parallel development in India for another type of a digital family of telephone switching systems, developed in the "*Center for the Development of Telematics*" (CDoT).

4.4.1. CDoT is a government-backed enterprise established in 1984 to design and manufacture prototypes of digital switching systems. CDoT is placed under the technical direction of Satyen (Sam) Pitroda, a switching expert with much experience in the USA. He came back to India in the early 1980s and, as a technical adviser to the Prime Minister, he succeeded in convincing the Indian Government of the necessity of establishing an R & D base in digital telecommunication technology if India wanted to become self-reliant in the new technologies. After a long battle, he succeeded in setting up CDoT to design and build *exchanges suitable for rural areas*.

An essential policy in the design of the CDoT products is to use for their manufacture a maximum of indigenous components produced by local and labour-intensive ancillary industries. Special emphasis was put:

- on simple assembly and test operation,
- on quality control and reliability, to be obtained by vendor qualification, plant visits and statistical lot sampling, inspection and card/frame/bay tests.

It is expected that between 1987 and 1990, the % of costs in indigenous Indian components used in the manufacture of the switching systems will increase from 50% to 90%. The management of the CDoT development project considers that this will pave the way for a new and more progressive technical environment in India.

The CDoT developed system had also to be designed for use under very specific Indian conditions. It has:

- to accept unsteady power supply, and have sufficient backup power,
- to function without air-conditioning and accept the tropical conditions in India: heat, dust, humidity, etc.,
- to cope with a very high traffic rate: 20 BHCAs per subscriber line in the cities,
- to be designed to need very little skilled maintenance.

4.4.2. The 512P module (i.e. a switch connecting 512P, P for "port" or subscriber line) is the basic building block of the CDoT DSS exchanges (DSS = Digital Switching System). The switching network of a 512P module is of T-S-T type. The switch is controlled by a Main Processor using a 16-bit microprocessor. The hardware of a 512P module is in a cabinet containing four terminal units, each of them handling 128 terminations, 8 terminations per card. In the periphery, a 8-bit microprocessor controls 128 terminations. In terminal cards and units, the 512P design uses firmware in assembly language. For call processing, maintenance, etc., the Main Processor uses a software developed in "C" language and to be later converted in Chill language.

Capable of intra-module switching, the 512P module has its own resources for tones, signaling, announcement and line testing. It can therefore be used as a stand-alone switch with the full complement of software including administration functions.

A configuration with an additional cabinet consisting of lines only and used for concentration of subscriber line traffic can serve 1024 lines or 256 trunk circuits.

The following multi-module configurations of this system are under development to provide:

- a "Main Automatic Exchange" (MAX) model, an assembly of 32 512P modules, offering without concentration a capacity up to 16,000 lines/trunk circuits, with prototype exchanges installed for test and evaluation in Delhi Cannit and in Ulsoor, Bengalore, in Summer 1987;
- another MAX model with a capacity of 32 000 lines plus 8000 trunk circuits, by doubling the number of time slots to 1024, and using concentration.

Another CDoT's development is the introduction of the CCS CCITT signaling system No.7 with a view of an ISDN access for digital lines of subscribers or PABX connected to exchanges of the new family.

4.4.3. An even more rustic and low-cost switch of the CDoT family is the Rural Automatic Exchange, the "RAX", a predecessor of the 512P-module system. Using digital switching of CCITT 32-channel PCM, a SPC control, two microprocessors (one for the control of the exchange, the other for the signaling functions), the "RAX" offers a capacity of 128 ports (max. 80 lines and 24 trunks). Its traffic capacity (1000 BHCAs) has been designed for the heavy traffic loads encountered in the Indian network: 0.1 Erlang per subscriber line and 0.8 Erlang per trunk line.

The first RAX was placed in operation in Kittur, Kamataka, in July 1986. Seven manufacturers have since been licensed to produce this system.

4.4.4. The CDoT expects to follow their present large production on the RAX with a series production of MAX exchanges and possibly a "TAX" transit system.

Putting into service a largely modular digital switching system is, however and as everybody knows, a difficult exercise, even with the high competence of Indian software experts. At the end of the 1980s, the future of the various digital systems in competition in India is seen as a very sensitive and controversial subject in India and its press. However, the Seventh Indian Plan of Development has called for the production capacity of the various versions of the CDoT system to be 500 000 lines per year.

5. People's Republic of China (PRC)

5.1. This country has sampled almost each of the major and many of the minor time-division digital switches described in this book. Nearly all the manufacturers of central office switches have made export sales of equipment to China, these sales being for different ministries and provinces.

5.2. China National Posts and Telecommunications Industry Corporation ("PTIC") is also the owner of 27 directly subordinated factories of telecommunication equipment and 10 specialized groups.

Among these factories, the Shanghai Bell Telephone Equipment Manufacturing Company ("SBTEMC") is a joint venture between PTIC and the Belgian BTM Company (Antwerp), which had been established by a contract signed in July 1983. The main activity of the Shanghai SBTEMC is the manufacture of the 1240 switching system (see Chapter IX-7) [6].

The first 1240 exchange assembled by SBTEMC was commissioned in the city of Hefei in the Anhui Province, on Dec.16, 1986. As

[6] At the time of writing, this system, completely manufactured in China, is only one of the many purchased to date by the many different PRC entities. Before the 1947 Revolution in China, the Shangai plant manufactured the Rotary system under a license of BTM, Autwerp (see Vol. I, Chapter IV-4).

stipulated in the joint venture contract, by the year 1990, the Shanghai SBTEMC is expected to reach an annual average level of production of 300 K lines.

6. Taiwan, China

Taiwan is one of the countries where design activities are progressing at the Telecommunication Laboratories of the Ministry of Communications. They have produced in the laboratory a system known as the Digital Switching System (DSS) [11].

At this date the Directorate of Taiwan Telecommunications, the Bank of Commerce and the Yao Hua Glass Co. have a joint venture with AT & T producing the No. 4 and No. 5 ESS.

GTE had a contract with Taiwan to produce the EAX GTD-5 system. However, these assets were taken over by Siemens and at the time of writing the fate of this contract is not known.

7. German Democratic Republic (GDR)

7.1. VEB Kombinat Nachrichtenelektronik (VEB KN) displayed at Geneva TELECOM 87 its first digital telephone exchange, the DVZ 2000 system. Earlier, at TELECOM 78, they offered a space-division system, the ENSAD [12], with digital signals passing through the sealed reed contact (ferreed type) switching fabric.

The DVZ 2000 is a terminal exchange intended to fit the needs of rural and small-town networks. The maximum configuration of the system allows for 10 000 subscriber lines and 1200 trunk circuits; however the optimal economy of this local exchange is considered to be obtained with about 4 000 subscriber lines and 600 trunk circuits.

7.2. The control of a DVZ 2000 exchange uses microcomputers in a distributed and decentralized architecture, with an interconnection of module units by 2 Mbit/s 32-channel PCM buses.

The DVZ exchanges are built in units allowing modular configuration and expansion: they may be configured with 4 to 64 line modules and a junction field. This field may consist of 2 to 16 junctor modules. The traffic loads per line/trunk circuit used in the design of the system and its modules are 0.17 Erlang per subscriber line and 0.7 Erlang per trunk circuit.

A subscriber line module is provided for 200 subscriber lines; it contains its own microcomputer, a first stage (concentration stage) of the DVZ switching network and a multifrequency signal-receiver. The trunk circuit modules are of two types: one for audio-frequency circuits connecting to electromechanical exchanges, the other for two 32-channel PCM 2 Mbit/s links. In the exchange, two other types of modules are also provided, the first type for auxiliary facilities, the second for man-machine communication obtained through an operator console.

7.3. The specification and design of the DVZ 2000 system have used the SDL CCITT language. The programming language of the system, except for some time-critical sections which are in Assembly language, is the CCITT CHILL language.

The DVZ 2000 has been designed to provide compatibility with CCITT ISDN, with introduction of specific modules for ISDN digital lines (2B + D subscriber line, and 30B + D PABX PCM link) and for signaling system No 7.

7.4. The first DVZ 2000 exchange to be commissioned in a public network was a Leipzig exchange of 2000 lines put into service at the beginning of 1988. A large number of exchanges of the system have been ordered by the GDR Deutsche Post and, in the export market, by the USSR Telecommunication Administration (in USSR, the DVZ 2000 exchanges will be known as YC and U1C1).

7.5. For very small rural exchanges and for low-cost extension of capacity of small exchanges, VEB KN has also developed another model of microcomputer-controlled digital exchange, the "OZ 100 D", allowing the connec-

tion of 96 subscribers and one service line. It can operate as an autonomous local exchange, a dependent exchange, or a sub-exchange. It can be used as an independent and unmanned satellite exchange to replace a circuit-concentrator. It is specially adapted for opening the telephone service in backward and far remote areas, when used in connection with a 10-channel PCM digital radio link. The system to be used in such an environment has been exported to various countries, e.g. Angola, Algeria, etc.

8. Finland

8.1. The DX200 [13] digital switching system produced by Nokia Telecommunications of Finland is the leading exchange family in this country, both in the number of exchanges and the number of connected subscriber lines. This development was preceded by the DX100 [14] which was the result of a technology transfer agreement with CIT-Alcatel of France based upon the E10B system which has an "action translator type" control. The DX200 system differs from the E10B since its control is based on stored program techniques.

The first DX200 exchange was placed in service in 1982. By 1987, over 400 DX200 offices were sold with 400K lines in service in Finland and 200K lines in six other countries.

The DX200 family offers a wide range of applications, from small and medium size local exchanges to trunk and transit exchanges. For public telephone network applications, three basic types of exchanges in the DX200 family exist:

- the DX 220 for medium-capacity local, trunk, and combined exchanges: from 500, up to 40,000 subscriber lines and up to 7,000 trunks;
- the DX 210 for small-capacity local, trunk, and combined exchanges: from 100, up to 4,000 subscriber lines and up to 480 trunks;
- a RSS for small-capacity (2.5 K Erlangs) remote subscriber stages: from 30 up to 250 subscriber lines, with up to four 2Mbit/s PCM links to main exchange.

Other specialized types of the DX 200 family also exist:

- a DX200 ISDN, a new member of the DX 200 family: two exchanges of this type have been ordered to be delivered at the end of 1988 to Finnish P&T and the Helsinki Telephone Company [7)],
- a digital cross-connect system, the DX200 DCS,
- a system, the DX 200MTX for mobiles, called the ECR900 for an European Digital Cellular network developed in a consortium associating Nokia, Alcatel and AEG (West Germany) and expected to have 500 exchanges with 750K subscribers by 1990.

9.2. Successful sales of the DX200 system outside of Finland have been in China (People's Republic of) (7 offices, for Oil and Railroad ministries), Nepal, United Arab Emirats (35 offices), Sri Lanka, Sweden (50 offices), Turkey (for mobiles), and Britain (to be distributed by STC, for special networks). Additional sales for the DX200MTX version have been reported for France and Algeria.

10. Denmark

10.1. Danish Telecom International A/S (DTI) is owned by the three Danish telephone operating companies for marketing products identified as Dikon. Since 1983 a Dikon line of switching systems have been jointly developed and produced by Jutland Telephone A/S, Triax A/S and Bang & Olufsen A/S. The most popular product has been the Dikon-RS. It is a remote line concentrator serving up to 480 lines, for use inside or outside of a central office building. Several hundred of these have been placed into service.

Initially the RS concentrator was developed to operate with the AXE system of Ericsson. It is the first example of a non-affiliated company developing an adjunct to an existing system requiring software. The Dikon group was not only

[7)] A 80 Kbit/s variety of digital subscriber line, called Diginet, was cutover in Helsinki in March 1986.

allowed by Ericsson to develop the software that resides in the AXE to control the RS, but, by data link between Sweden and Denmark, the engineers used the Ericsson software development tools.

10.2. In parallel with the RS development, the Dikon group designed a "controlling exchange" (CE) to be used with the RSs, independently of an AXE exchange. The association of a cluster of RSs controlled by a CE could serve a maximum of 3,000 lines and 300 trunks. About 20 CE switches have been placed in service. About 25% of the Danish RSs are controlled from CEs, the rest from AXE hosts.

Other developments in the Dikon family include the MX (a smaller 60 line concentrator), the LE (a stand-alone, local exchange version of the RS), and eventually the TE (a transit exchange). About ten LEs were placed in service by 1988.

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Part X

Signaling in the electronic era

CHAPTER X-1

SOME THOUGHTS ON SIGNALING

1. Telephone signaling, a rather esoteric technique

1.1. For occupation or distraction, women had – or still have – knitting and crocheting. Bridge and chess also have their enthusiasts. One has to be initiated into these games or exercises in order to acquire a taste for them: one has to know the rules and master the subtleties. The keenest adepts are catered for by special sections in good newspapers as well as by specialized magazines. For an outsider, such subjects are incomprehensible and the jargon a closed book.

Nowadays, we go one better, and the personal computer is all the rage. There is no shortage of customers for these little electronic wonders, on sale at every corner of the busy streets in large towns. In bookshops and at newspaper stands there is a proliferation of magazines in completely esoteric language. And these computer buffs feel they belong to an elite class of the intelligentsia!

1.2. Telephone signaling is a discipline rather like those mentioned above. It also has its initiates and its fans. To tell the truth, they are fairly thin on the ground: in each country of some size, you can almost count them on your fingers. As you see, it is a select club. The total in the world amounts to no more than a small tribe of Indians scattered over the five continents.

The subject is far from being straightforward. One must have a good measure of patience and quite a bit of practice to grasp the finer points of the game – which is played rather like tennis. Instead of a ball hit from one end of the court to the other, messages fly between the ends of a channel, which takes the place of the net, separating the partners involved. The channel can be seen as a virtually non-existent, abstract barrier. In actual fact, it may be anything from a signaling "bus bar" only centimeters long in a telephone exchange to an intercontinental circuit 10,000 or 20,000 km long.

Belonging to a club as select as the telephone signaling one undoubtedly has some advantages. For example, one can reach international level very quickly! This will provide the opportunity to take part, time and again, in international tournaments where everyone fiercely defends the merits of the system proposed by his own country. For anyone interested in long-distance travel, this may not be unpleasant.

1.3. Conversely, there is one major disadvantage. Apart from the initiates, the happy few, no one is interested in the subject. All that telecommunication professionals and ordinary folk want is a system which works and can be used just by giving it a serial number. In telecommunications, knowing three or four of these magic numbers is sufficient proof of the highest professionalism.

So it is not surprising that there is very little technical literature on signaling. A few articles in technical journals. A few books [1] ... They are not best sellers and publishers will certainly not make

[1] In this virtual desert of works on telephone signaling, an exception to which the professional can usefully refer to is the book by S. Welch [1]. Since it is a 1979 issue, a new revised edition would be welcome because of the speed at which telephone signaling has developed during the following decade.

fortunes out of them. The writers, too, have a difficult and trying time in explaining and instructing the principles of signaling and the modes employed.

2. Signaling, an essential feature of switching. Thanks to the CCITT, an international consensus on its modes

2.1. Despite the esoteric nature of the subject, telephone signaling and the history of its development since 1960 [2)] merit to be better known. Telephone switching could not exist without telephone signaling, which is essential for an exchange to communicate with the outside world. It works in both directions – for receiving and for transmitting:

- like the lungs circulating air to all parts of the body, signaling provides the telephone exchange with the messages and signals from all sources – human or mechanical – wishing to communicate with it;
- like an executive arm, signaling sends off the decisions and instructions of the telephone exchange.

2.2. So as not to overtire the reader, this Part of the book will be restricted to describing the main achievements since 1960 in reaching international consensus on telephone signaling modes.

A very clear characteristic of the new direction taken by telephony since 1960 and of the worldwide extension of the telephone network must be mentioned in the first place. There are now no longer any specifically national studies on signaling which are not basically determined by the international research carried out mainly by the International Telegraph and Telephone Consultative Committee (CCITT) and its Study Group XI ("ISDN and telephone network switching and signaling").

[2)] The book "100 Years of Telephone Switching (1878–1978)" [2], pp. 303–351, gives its history which is equally complicated and difficult to follow, from its beginnings in 1880 until 1960.

We shall mention briefly the basic principles of the successive modes – increasingly rich and sophisticated – permitted by advances in electronics but shall avoid going into too many details: an entire book would not suffice. Anyone who wants to know the design details has to turn to the professional's "bible", the CCITT publications, updated and produced with a different colored cover every four years (in 1985, Fascicles VI.1 to VI.8 of the Red Book; in 1989, idem, in the Blue Book).

2.3 The account below is essentially historical and has the advantage of constituting a tribute to the CCITT's work in the international standardization of signaling practices. For the CCITT, it is a long-term task which has gone for decades and for which all credit is due to the past and present members of Study Group XI, as well as to its competent and farsighted Chairmen:

- W.S. Tobin (United Kingdom), 1960–1968
- A. Jouty (France), 1968–1972
- J.S. Ryan (United States), 1972–199x

who, each in his turn, managed to guide the Study Group's deliberations around numerous obstacles and conflicting opinions.

2.4. Progress in international signaling since 1960 can be divided into three stages corresponding to Nos. 5, 6 and 7 of the CCITT series of systems.

Each of these stages is dealt with in the following Chapters. Chapter X-3 covering Systems Nos. 5 and 6 also contains a section on the official adoption by the CCITT of its so-called Systems "R1" and "R2" (regional 1 and regional 2) which, ultimately, had the widest application.

Chapter X-6, based on the example of the AT&T long-distance network, describes all the advantages and virtualities afforded by common channel signalling (CCS) to obtain a "stored program network".

Chapters X-8 to X-9 describe subscriber line signaling, from its traditional and simplest form – the analog one – to its present and most sophisticated form: the digital one for ISDN subscribers.

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CHAPTER X-2

1961–1964: INTERCONTINENTAL SYSTEM No. 5

1. The first intercontinental submarine telephone cable, TAT 1, was laid across the Atlantic between Scotland and Newfoundland in 1956. As the fruit of lengthy research in both the United States (AT & T Bell Laboratories and AT & T Long Lines) and the United Kingdom, it was an event of great historical significance and was loudly heralded at the time. The telephone no longer served strictly compartmentalized markets but was becoming universal ...

In point of fact, TAT-1 provided only 48 circuits on four 12-channel groups and with a channel passband of only 3 kHz. However, the newly AT & T-developed TASI (time-assigned speech interpolation) system soon enabled its operational capacity to be increased to 76 circuits. Much of the success of TAT-1 was due to the fact that its circuits were of excellent quality, far superior to that previously offered by the few radiotelephone circuits open between North America and Europe.

A whole series of transatlantic submarine cable systems were subsequently put into service (see Table 1). Their purpose was to meet an almost insatiable demand for transatlantic telephone calls.

2. Once the first high-quality transatlantic circuits had been put into service, their owners set about improving the efficiency of their operation which initially was manual. This necessarily entailed turning as quickly as possible first to semi-automatic and, later, to automatic service.

The aim was therefore to devise a system which would ensure communication between automatic networks of substantially different design on either side of the Atlantic.

3. The task was swiftly carried out by a very small team of experts representing the United States (AT & T), France, the Federal Republic of Germany and the United Kingdom.

Thus the "interim transatlantic system" was built without regard to broader and more official international bodies such as the CCITT. The system was a compromise between American

Table 1
Transatlantic Cables of the 1960s

Cable name	Year terminal laid	Countries	Route length (nautical miles)	Basic system capacity (3 kHz circuit)	Total circuit including TASI
TAT-1	1956	Canada–United Kingdom	1942	48	76
TAT-2	1959	Canada–France	2205	48	76
CANTAT	1961	Canada–United Kingdom	2072	80	117
TAT-3	1963	United States–United Kingdom	3518	138	175
TAT-4	1965	United States–France	3675	138	175
TAT-5	1969	United States–Spain	3270	720	–

technologies and trends and those in favor at the time in Europe. Simplicity of design was the guiding principle both to ensure rapid decision making and to facilitate physical construction of the terminals of the system, whose main features were:

- line signaling to afford two-way circuit operation (an American practice, doubly warranted here by the need to improve the operational efficiency of circuits which were both costly and few in number);
- multifrequency code (MFC) inter-register signaling using only MFC signals in the forward direction to transmit the address signals (digits of the called number).

The interim transatlantic system was brought into service on March 30, 1963 to provide semi-automatic service on relations between:

- New York–London
- New York–Frankfurt-am-Main.

4. The CCITT, i.e. the new ITU Consultative Committee [1], born of an amalgamation of the CCIF (telephony) and CCIT (telegraphy), held its first Plenary Assembly at New Delhi (India) in 1960. No venue could have been more propitious. Far from Europe where all Plenary Assemblies of the ITU Consultative Committees had been held since 1925, New Delhi established the universal scope which these Committees were to have in future and:

- which no longer was confined to Europe;
- but extended to all countries: those of North America, which began to send extremely large delegations, those of Asia which were widely represented, particularly Japan, those of Latin America which entered the international scene, and above all a large number of countries which had acceded to independence in the 1950s.

5. The opening of transatlantic submarine cables, the plans for laying transcontinental cables across the Pacific and the prospect of satellite communications following the placing in orbit of the first satellite, Sputnik (USSR), in 1957 made it imperative for the CCITT to define the operational and signaling characteristics of an intercontinental telephone service.

5.1. The task of harmonizing the service's operational modes was entrusted to the CCITT "telephone operation and tariffs" Study Groups. The operational modes differed appreciably as regards charging methods, the facilities offered to users and terminology, according to where American practice was followed or that defined by the CCIF for an "international" service, which in fact was seldom applied outside Europe. The task was accomplished very gradually in two stages:

- definition in 1964 of the "Instructions for the intercontinental service";
- fusion in 1968 of the modes of the "intercontinental" service and the so-called "international" service (operated essentially in Europe).

5.2. CCITT Study Group XI was instructed to specify the characteristics of an intercontinental signaling system that could be applied universally and not solely over transatlantic submarine cables.

6. Study Group XI, which at the time was also researching many other subjects, delegated the task of establishing the specifications to one of its Working Parties under the chairmanship of C.H. McGuire (Canada). The Working Party became a veritable kingdom, monopolizing the attention and the meager resources of the CCITT.

Under the chairmanship of W.S. Tobin, Study Group XI enjoyed moments of glory and liked to travel: it met at Montreal (1962), Melbourne (1963), and then, during the next CCITT study period (1964–1968), in New York (1966), Tokyo (1967) and finally Mar del Plata, Argentina

[1] A very brief and purely formal Plenary Assembly had been held in 1956 for the exclusive purpose of establishing the new Committee. This two-day Assembly had been preceded by the final Plenary Assemblies of the International Telephone Consultative Committee (CCIF) and of the International Telegraph Consultative Committee (CCIT), now defunct, which had dealt with all matters then within their competence.

(1968). The considerable amount of work achieved at all those meetings for signaling was effected in two stages:

- 1961–1964, examination of existing systems, including the interim transatlantic system, to see whether they were fully suitable for automatic intercontinental operation;
- 1965–1968, following the approval of Systems No. 5 in 1964, consideration of the specifications for a more modern system to replace it or, if possible, improvements to that system.

7. Serious discussions on the future CCITT intercontinental system thus began in Montreal in 1962. As is customary when a system has been defined, particularly if it is done by a very small group of experts, criticism of the "interim system" was soon forthcoming and, at times, was even acrimonious. Everyone who had not been present at the discussions during which the system was adopted, or whose proposals had been brushed aside for reasons of expediency due to the urgency of the decisions needed, launched an attack on the system, claiming that:

- it was not suitable for transit operation;
- the signaling times, particularly the time to transmit the answer signal and the post-dialing-delay (PDD), were too long;
- while it could provide semi-automatic operation, relying on the patience of the outgoing international exchange operator, the system would not permit automatic intercontinental operation, for which there was an urgent demand.

Despite angry discussions, the interim system withstood the assault:

- the disadvantages claimed were unlikely to prevent its immediate use in semi-automatic operation;
- a few minor alterations involving certain parameters relating to signal transmission time would reduce difficulties arising from signaling delays;
- experience gained from the opening – already scheduled – of fully automatic service on two transatlantic links would, more than any amount of discussion, reveal user reaction to the new "interim systems", however imperfect it might appears in the eyes of its detractors.

Such operating experience was gained in 1963 and 1964 in real commercial service conditions. It showed that, despite the misgivings at Montreal in 1962, the interim transatlantic system would not be confined to the semi-automatic service alone. The modifications called for at Montreal to reduce signaling delays were introduced following studies carried out from 1962 to 1964.

Thus, by 1964, all the conditions were ripe enough for the CCITT to approve the interim system as an intercontinental system and to publish its specifications. The system was then officially baptized CCITT System No. 5. The labor pains were attended by the felicitous initiative in 1963 to assign simple numbers in chronological sequence to the successive CCITT systems. This had the tremendous advantage of dispensing with the need for long and complicated names.

8. Once established, System No. 5 enjoyed great success that, even 25 years later, it still endures. There is not a country in the world, even among the least developed, that does not use the System No. 5 terminal equipment in its international/intercontinental exchange.

The prodigious growth of intercontinental circuit between 1965 and 1975 was largely due, particularly in the developing countries by then linked with the rest of the world, to the introduction of satellite systems, especially those of the International Telecommunications Satellite Organization (INTELSAT). Owing to its simplicity, e.g. the absence of compelled signaling between signals from opposite directions, System No. 5 was in no way disadvantaged by the long propagation time over satellite circuits and proved perfectly suited to the satellite transmission mode.

CHAPTER X-3

1964–1968: CHOICES FROM A RANGE OF OPTIONS

1. Trends in 1965

1.1. The CCITT considered at its IIIrd Plenary Assembly in 1964 that a more modern and elaborate system than System No. 5 would be worth studying.

An apparently promising new technique borrowed from advances in data communications consisted in routing signals, not on an associated channel basis as had always been the case, but over a common signaling channel serving a large group of circuits.

The technique was already in the air and the military were interested in it for their long and very long-distance networks. Although such projects were never mentioned in the CCITT, their influence may have been considerable by osmosis from studies conducted independently but along the same lines... In any case, the go-ahead was given for large-scale studies at civilian level in what had until then remained a completely virgin field.

1.2. The desirable options for a new system were defined with much hesitation.

Two potentially conflicting trends emerged immediately between:

- those in favor of a system of completely original design, and
- the "traditionalists" who preferred to follow the more conventional path of channel-associated MFC signaling.

In addition, there was initially some uncertainty as to the real aim. Was the system to be purely intercontinental or should it be of universal application both for intercontinental relations and for the infinitely heavier traffic in intracontinental relations?

1.3. European member representatives usually outnumbered the others at CCITT meetings. Their desire to see the CCITT System No. 4 – the one used in Europe over international traffic routes – replaced fairly quickly far outweighed their concern to define an excellent new intercontinental system. System No. 4 was becoming dated, having been designed at a time (1948–1954) when MFC signaling was regarded in Europe as an unaffordable luxury. Moreover, intercontinental circuits in the European countries accounted for only a minute portion of their international circuits.

1.4. Advanced research into what was known as the "European" system, later as the "Bern" system (from the name of the Swiss capital city), and which finally became CCITT System "R2", had originally been prompted by the Netherlands Administration and the laboratories of Bell Telephone Manufacturing Co (BTM) of Antwerp.

This non-CCITT research had been initiated in 1960 and followed a fairly tortuous path. Admittedly, a few basic design principles including compelled signaling had quickly been defined, but the complexity of the system envisaged and the multiplicity of constraints imposed in Europe by the diversity of automatic national networks required change after change in the specifications. The electronic components technology used for constructing registers was developing extremely fast and constantly offered possibilities for enriching the system. Eventually, it

was these advances which determined its competitiveness and economic advantages.

Although a few industrial groups – particularly L.M. Ericsson – quickly realized the value of standardizing a modern MFC system, many other such groups in Europe had misgivings or held themselves aloof from the research.

These studies for a European MFC system seemed interminable, involving innumerable modifications and one version after another of the specifications. This was particularly true when they were seen from the outside, as they were by many experts since the CCITT had no part in the discussions.

Although merely alluded to at CCITT meetings, the research was much in the minds of many delegates. This explains why the representatives of European countries mostly favored CCITT research based on the traditional technology of channel-associated MFC systems.

1.5. The years 1965–1966 saw the introduction of possibly pragmatic but certainly short-sighted proposals for "hybrid systems".

This would have meant designing a system intended solely for signaling between MFC registers. It would have been grafted onto on or other of the line signaling systems then current, i.e. System No. 4, or System No. 5 or even the national signaling systems which were more or less closely related to each other.

The temptation to adopt hybrid systems is a permanent feature of international life. As soon as an international system has been officially approved, the partners in the international service find excellent economic reasons for preferring to tinker with the equipment of their own national service and adapt it more or less efficiently to the international characteristics defined. Thus hybrid systems for introducing the automatic international service as quickly as possible flourished in Europe between 1958 and 1964. After some time, however, it was necessary to revert to circuits that conformed to international specifications. These hybrid circuits of the 1960s had major disadvantages, particularly the sudden cuttingoff of calls as a result of the called subscriber's speech currents imitating the clear back (hang-up) signal.As initially envisaged, the common channel Signaling System No. 6 was also of hybrid design:

- the address signals [1], i.e. the inter-register signals of MFC systems, were to be transmitted over a common data transmission channel;
- the line signals would continue to pass over the circuit used as the speech channel.

2. *Clear pattern emerges in 1966*

2.1. The New York meeting in 1966 [2] sorted out the welter of suggestions put to it, clarified matters and defined basic options:

a) System No. 6 would not be a hybrid and its line signaling would be over a common channel like the address signals;
b) to satisfy the proponents of MFC signaling, a System No. 5 *bis* using far richer signaling between registers than System No. 5 would be studied. Its MFC signaling code would have to produce the same signals as those of the future System No. 6.

2.2. The objectives briefly outlined above naturally did not clear away all difficulties. A particular source of discord was the limit for PDD, a factor which was regarded as critical for user reaction to the automatic international service and the satisfaction it would give him.

A common channel signaling system (CCS) is by nature a "link-by link" system. At each intermediate point (transit center) of the call, the information must first be processed there before being transmitted over the next link of the connection.

Speech channel MFC systems, at least in the design which was prevalent in Europe, were "end-to-end" systems in which most of the information transmitted in MFC does not have to be received and processed at an intermediate transit

[1] Meaning both forward address-signals and characteristic signals of the called station in the backward direction.

[2] All the meetings mentioned hereafter are those of CCITT Study Group XI.

center but is transmitted directly to the terminal exchange over the connection already established. Obviously, this procedure substantially reduces the PDD.

The merits of end-to-end and link-by-link signaling were fiercely debated by their respective supporters between 1962 and 1968.

The results of trials of System No. 6 during the period 1968–1972 brought these doctrinal quarrels to an end: given appropriate technology, extremely short PDDs could be obtained with a link-by-link arrangement like the CCS system.

The quarrel had sometimes been referred to as a "theological" one, between "idealists" who believed that a single system could be universally adapted and "pragmatics" who took the line that the mosaic of automatic national networks demanded the coexistence of many signaling systems and therefore the complete processing of information at transit centers where incoming and outgoing signaling systems were of different types. May the lesson taught by the latter, based as it was on a realistic view of the international situation, be remembered in future and prevent the link-by-link/end-to-end quarrel from resurfacing to embroil international discussions!

2.3. The Tokyo meeting in 1967 confirmed and clarified the options taken in New York the previous year. The MFC signaling examined by Study Group XI was to relate exclusively to improvements in System No. 5 and there was no longer any question of grafting it onto the System No. 4.

The development of System No. 6 had been carried out energetically and expeditiously. The Nippon Telegraph and Telephone Corporation (NTT) was already able to present a working laboratory model of the system to participants at the meeting.

"Never had the entire world's leading telecommunication laboratories engaged in such active cooperation. Whereas generally these were reluctant to reveal the results of their work prematurely, usually to protect their patents", all partners in the research on System No. 6 laid their cards on the table, and contributed constructively.

Numerous Working Party meetings such as those in Prague and Stockholm, culminating in one at Florence in the autumn of 1967 at which a "conclave of seven experts" virtually closeted itself to draft the specifications of System No. 6, had to be held before the specifications could be submitted to the CCITT Plenary Assembly at Mar del Plata (Argentina) in the autumn of 1968.

2.4. Chapter X-4 is devoted entirely to the design of System No. 6, which must be regarded as one of the "founding stones" of telecommunications technology for the remainder of our century. Moreover, the methodology and the intellectual efforts applied in developing the first CCS system deserve mention in this book, for the benefit of the engineer interested in switching techniques.

2.5. The supporters of a modern version of the MFC system had worked concurrently with those researching System No. 6 and submitted their specifications for System No. 5 *bis* to the same 1968 Plenary Assembly.

The specifications of both Systems No. 5 *bis* and No. 6 were approved and published by the CCITT. While the specifications of System No. 5 *bis* were immediately applicable, those of System No. 6 had first to be subjected to in-service tests in accordance with detailed proposals scrupulously drawn up by Study Group XI to meet commitments by nine countries which had volunteered to organize the tests. The tests are described briefly in Chapter X-4.

3. Unexpected adoption at Mar del Plata (1968) of two additional CCITT systems: Systems R1 and R2

3.1. Quite unexpectedly, the CCITT Plenary Assembly at Mar del Plata was somewhat abruptly presented with a proposal by certain Latin American countries for the recognition, approval, specification and standardization by

the CCITT of the "European MFC" system. In many respects this differed from System No. 5 *bis*. The target for a CCITT adoption of the European system meant the standardization of the MFC systems produced by different European manufacturers whose leading clients were countries which had started automating their national networks only in the mid 1960s. This was particularly true of South-East Asian countries and many in Latin America.

Introduced somewhat haphazardly, all the MFC systems exported to these countries incorporated the more or less appreciable differences to meet the more or less ambitious special requirements of the local authorities. In the case of Brazil, it was not a matter of differences simply between versions going to different countries but between versions ordered by the telephone enterprises which operated independently in different regions of that vast country, at a time before structural reforms had led to the inception of Telecommunicacoes Brasileiras SA (TELEBRAS), now Brazil's central administration.

The diversity of the MFC systems delivered outside Europe made interworking between them virtually impossible without expensive modifications that it would have been hard to devise and, naturally, every owner of an MFC system wished to preserve its essential characteristics.

Some standardization of these MFC systems was therefore inevitable if they were to be used for international operation, and their manufacturers were all in favor of it. Who had more authority than the CCITT for effecting their standardization?

3.2. After much hesitation, Study Group XI had, prior to the Mar del Plata meeting, agreed to a "back-door" procedure for publishing the specifications of the European MFC system in the CCITT books. In fact they were to appear as a purely documentary "Annex".

At Mar del Plata, however, the system acquired a radical change of status. A delicate question for the CCITT: conceived entirely outside the CCITT, should this "illegitimate child" be recognized by the CCITT?

The European countries themselves had become fully convinced that the introduction of the system at home would be advantageous at international level and, in some cases, even at national level. Their conviction was based both on financial considerations and on the modernity of the system: with advances in electronic components, it could be obtained at low cost and offered a wealth of signals and thus vast operational potential.

3.3. As is traditional in the CCITT, a happy compromise was reached at Mar del Plata:

a) the CCITT would recognize the "European/Bern" system but simply as a "regional system";
b) it would also recognize the MFC system developed by AT&T and operated in North America as the American SF.1, as another "regional system";
c) on account of its seniority and far more widespread use, the latter system would be known in the CCITT as "System R1" (R for "Regional") and the European System as " System R2".

4. Fate of the systems standardized At Mar del Plata in 1968

4.1. In signaling matters, Mar del Plata proved both generous and fertile in generating official CCITT systems, the four offsprings being:

- System No. 5 *bis*,
- System No. 6,
- Systems R1 and R2.

4.2. System No. 5 *bis* was in fact stillborn and was never applied. After some hesitation it was eventually dropped from the CCITT's publications.

4.3. System No. 6 started life with the series of in-service tests mentioned in Chapter X-4. In 1974 it found – in North America even more than at international level – a vast field of application in an American version known there as CCIS (common channel interoffice signaling).

4.4. System R1 had already put down strong roots in North America, where it continued to expand moderately before being supplanted by the CCIS system.

4.5. The European regional System R2 spread throughout every continent but not in North America or Japan. Besides the Latin American and South-East Asian countries already mentioned, where MFC systems were gradually brought into line with CCITT System R2, the countries of Africa made R2 their standard national system as did most of the Middle-Eastern countries.

CHAPTER X-4

A HISTORY OF CCITT SYSTEM No. 6

1. International studies in 1960–1964. Design principles of CCITT System No. 6

1.1. The account given here of the birth of System No. 6 in the period 1960–1964 may appear somewhat lengthy and overly detailed. The description of the way in which System No. 6 was developed, however, provides a fair model of the way any complex system is constructed. It could serve as an illustrative case study for the training of young engineers, for several reasons:

a) although the system to be created was complex, it was not excessively so. It remained, so to say, on a human scale, in no way comparable, for instance, to the Apollo project which in the same period was preparing to take man to the Moon;
b) the project fitted between clearly defined time limits. The specification of System No. 6 was launched by the IIIrd CCITT Plenary Assembly in 1964 for completion by the IVth Plenary Assembly (Mar del Plata, October 1968);
c) unlike many other complex systems, designed for military use or produced as a result of secret research in industry, all the development stages of this project took place in full public view, with a wide distribution of documentation;
d) the "case" is now of historic interest only, and it is always easier to dissect the dead than the living!...
e) the literature concerning the project is abundant and easily accessible (see in particular the special number of the ITU "Telecommunication Journal" devoted to the subject [1]). Also one of the fascicles of Volume VI (Fascicle VI.3) of the CCITT Red Book gives a detailed description of the system's specifications;
f) lastly and above all, the fact that the design principles of System No. 6 were, and still are, of prime importance. They are those of the North American "CCIS" signaling system, one of the major structural components of the United States long-distance network. With some adjustments, the same principles were also used from 1976 onwards in the design of CCITT signaling System No. 7, which was to become one of the essential elements in the evolution towards ISDN systems.

1.2. Studies for System No. 6 were conducted on a multinational basis. This approach has become increasingly prevalent in the 1980s, especially in aeronautical (e.g. the Airbus) or space projects (e.g. Spacelab, Ariane). Fifteen years earlier, this was very unusual.

The contributions provided by a great variety of sources, by the many participating countries, considerably enriched the skills employed in designing and launching the system. On the other hand, there was no top hierarchical authority to make quick choices between alternatives which at first sight offered equal advantages. Decisions were only reached after all arguments concerning respective merits of the different options (or their advocates) had been exhausted!...

1.3. The creation of System No. 6, a model of international cooperation, was duly celebrated between 1970 and 1975 in a multitude of articles. This abundance was especially remarkable and contrasts with the usual shortage of technical literature devoted to the highly specialized field of signaling. As a result, this account has been able to draw on many excellent reports, including in particular those of A. Jouty and G. Le Strat [2] and J.S. Ryan [3] (see also [4]).

1.4. For the reasons mentioned in paragraph 1.1 above, this account is presented in a fairly didactic form. It attempts to illustrate the underlying pattern of the system's architecture, as well as that of its basic "sub-system", i.e. the data link used for common signaling channel.

In any account drawn up after the event, the sequence of steps which led to the design of a new system appears as the product of coherent

and relatively simple logic. Actually, System No. 6 was built up in bits and pieces. It was produced by specialists working in their own fields and tackling the problem on extremely different fronts. For many of them, the beautiful logical simplicity of the system was far from evident when they attended the CCITT meetings. Nevertheless, each workman did his best in his own field and stone by stone the specifications of System No. 6 were built and completed by 1968, within the time limit set four years earlier.

2. Design constraints and state of technology in 1965

2.1. With its study of System No. 6, CCITT Study Group XI had embarked on an adventurous voyage. It was a bold undertaking and they had to navigate through seas which were still completely unexplored.

A considerable number of guidelines and constraints had to be laid down. At the 6th International Teletraffic Congress in Munich (1970), E.P.G. Wright (Standard Telephones and Cables plc = STC, United Kingdom), one of the most esteemed pioneers among these navigators, presented a graph in the form of a compass rose, which perfectly illustrated the multiplicity of these constraints (Fig. 1).

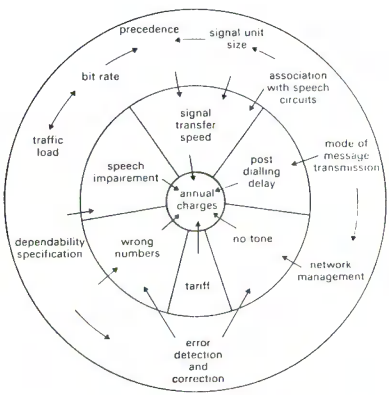

Fig. 1. System No. 6 design complex (figure extracted from E.P.G. Wright's article submitted to the 6th International Teletraffic Congress (Munich, 1970) [5]

2.2. It was also the first time that the CCITT had to create a system from scratch. Until then, the deliberations of its predecessor, the CCIF, and thereafter of the very young CCITT in its early days, had remained somewhat academic. They generally went no further than endorsing, with a few finishing touches, some system submitted by one of the administrations, often bearing the hallmarks of its national origin.

There was, therefore, quite a radical change in international working habits. With hindsight, this injection of new energy and new blood in the CCITT's activities can probably be attributed to the arrival in force of North American and Japanese partners, whose motivations and whose forceful and constructive enthusiasm may be explained by the opening and explosive development of intercontinental telephone relations.

2.3. For its navigation, the instruments available to Study Group XI were the most advanced that technology had to offer in the mid-1960s.

It may be interesting at this point to situate that technology chronologically. The situation in that period was in a state of flux and evolved rapidly year after year. What now seems obvious had only just been achieved in the fields of switching and data transmission.

Study Group XI began its studies in 1965, when the first SPC exchange, AT & T's ESS No. 1, had just made its first appearance. The term "processor", fundamental in the terminology of System No. 6, had only just been coined.

Data transmission was still at the stage of incipient commercial take-off. In the wake of the rapid development of the computer industry, and hence following it, the commercial use of data transmission had only just begun to spread. An outline is given in Box A of the rapid progress achieved in data transmission since the early 60s.

3. Design of the "data link" sub-system

3.1. The data circuit constituting the common signaling channel of System No. 6 was subject to the following requirements:

- it had to operate with the highest bit rate possible;
- it had to include a coding system for detecting errors in message bits;
- it had to be associated with a means of correcting those errors.

3.2. When the study of System No. 6 began, the modulation rate of data transmission circuits in commercial service rarely exceeded 1200 Bauds ("Bds").

The technological advances (as mentioned in Box A) had duly produced their effect within the CCITT, where the Study Groups responsible for data transmission were among the most active and the best attended. During the study period 1965–1968, at the same time when the characteristics of System No. 6 were being defined, the CCITT standardized modems providing 2400-Bd modulation. This range, which was the highest so far defined for CCITT modems, was eventually selected for System No. 6.

3.3. The bit stream transmission rate and the constraints defining maximum signal error rate limits (Box B) in turn determined, according to the BCH error detection coding chosen (see Box A, paragraph 5), the division of the data link bit stream into blocks and signaling units, in other words, the *format of the signal units*.

For a signal unit, the random bit error rate is proportional to its length. The unit's format therefore had to be kept reasonably short, and

Box A

State of data transmission technology in 1965

1. Data are transmitted over a telephone circuit through modems located at each end of the circuit, the latter being generally a point-to-point leased circuit, requiring special maintenance.
2. A considerable fund of statistical data had been patiently assembled, especially by the CCITT, concerning disturbances – noise and short interruptions – on telephone circuits, which can give rise to errors in bit streams.
3. These statistics showed that errors were caused mainly by two phenomena:
   a) background noise, causing errors spread randomly over the bit stream;
   b) noise bursts causing error clusters in the bit stream.
4. The statistical distributions of these two types of error had been sufficiently and accurately determined for telephone circuits, making it possible to deduce the probable error rates for bits transmitted over a data link.
5. Elaborate coding techniques had been defined to detect such errors and either to have them corrected automatically, or to have the incorrect messages retransmitted. For this purpose, bit streams were divided into blocks of bits, to which parity bits were attached. Following the footsteps of R.W. Hamming (1950) and of many other scientists after him, Bose, Chaudhiri and Hocqenguem, using subtle algebraic theories, had devised a code by 1959 which ensured excellent detection of error clusters and their automatic correction. This code became so well known that it was referred to by its simple acronym BCH, made up of the initials of the three names, as an unusual mark of recognition. It was a BCH-type code which eventually was used for the data link of System No. 6.
6. Another extremely troublesome type of disturbance, which gave rise to uncertainties concerning the recognition of a bit transmitted on line, had also been overcome. At the receiving end of the line, there is a slight time lag in arrival between the different frequency components of a binary signal. The "eye pattern" is disturbed as a result, hence the uncertainty affecting bit recognition and an effect known as intersymbol interference. In 1964, R.W. Lucky found a means of equalizing these distortions, thus opening the way for a substantial increase in the modulation rate of data transmissions.

Box B

Expected error rates considered in 1965 (upper limits)

1. Bit error rate on the data link: 1×10^{-5}
2. Signal unit error rate: 1×10^{-4}
3. Error detecting code and data carrier failure-detector should provide an undetected signal error rate of: 1×10^{-8}
4. And for the few signals which might seriously affect customers (i.e. false charging or disconnect), an error rate of: 1×10^{-10}

the number of information bits contained in the unit had to be the smallest possible which was still compatible with the desired complexity of the signal code. That number further determined the number of parity bits required for the BCH coding chosen. After much hesitation, it was decided that a signal unit should have 28 bits, made up of 20 information bits and 8 parity bits, which was a compromise between several stoutly defended proposals.

3.4. The data packet transmission mode had not yet seen the light of day or at any rate had not yet taken shape. By a process of implicit reasoning identical to the attribution of an address to every data packet, the signal unit of System No. 6 had to identify unequivocally the circuit to which it was assigned. The number of the circuit was contained in a *label*, which was placed at the beginning of the signal unit.

Common signaling channel was intended theoretically to operate with a number of circuits greater than 1000. As $2048 = 2^{11}$, 11 bits were needed for the label. With a further opening bit identifying the next 11 bits as the label, there were only 8 bits = (20–12) left for the signal information required to set up a call on the circuit.

3.5. A signal unit format with 20 information bits, once the label bits were taken out, meant that address signals could not be transmitted with a *lone signal unit. Multi-signal units* had to be used, involving a number of single units to be associated to, and behind, the same label to avoid the repetition of the latter in the heading of each single unit.

3.6. The error correction system was based on the *retransmission of any signal unit* identified *incorrect* on reception. Signal units therefore had to be identified according to a serial number at the transmitting end, where they were held in a buffer store until all units had been acknowledged as having been received correctly.

The need for a simple way of identifying successive signal units required superimposing on the structure of single or multi-unit messages a second structure for the detection of signal units, which consisted of grouping a number of units into *blocks*. A block in System No 6 groups 12 messages ("signal units"):

- 11 signaling message,
- and a 12th message ("ACU" = ACknowledgement Unit)) consisting in acknowledgments for the 11 preceding messages received from the opposite end.

3.7. Since the data link was operated synchronously, signals had to be transmitted continuously even when there was no useful information to transmit. This task was performed by "*synchronization signal units*" (SYUs), all with the same characteristic bit coding and serving two purposes:

- the first one, – arising from their specially designed characteristic coding –, of providing the receiving end with a convenient way of maintaining bit synchronization for both signal units and blocks;
- the second one, of acting as "fill-in signals" in a block in the absence of signal units carrying information concerning a telephone call.

SYUs fitted into blocks just like any other signal units. They generally occupied a very large part of the bit stream of a data link. Like other signal units, they were acknowledged, but,

unlike other signal units, were not retransmitted in the event of a negative acknowledgement.

3.8. Such in rough outline was the architecture designed for the system's common signaling channel. One illustrative, though theoretical, example of the information flow carried by the bit stream of a data link is given by A. Jouty and G. Le Strat in [2]:

> "A data link serves a group of 1500 circuits operated both ways. Each of these circuits handles call after call practically continuously. The average duration of calls, including unsuccessful calls, is 3 minutes. Each call requires on average the transmission of 10 signal units, each lasting 12 milliseconds. The data link load is then only 50% and about half the signal units are used for synchronization (SYUs)."

4. Architecture of the signaling network

4.1. Many other considerations apart from those relating to the data link entered into the design of System No. 6, and they were all related to matters so far completely unexplored. At the outset, one major problem had to be overcome: the vulnerability of a system in which the operation of a considerable number of circuits depended entirely on the satisfactory functioning of the data link. The problem was somewhat reminiscent of the difficulties which can be caused in an SPC switching system by a failure of the central processing unit.

A whole range of safeguards was established to offset the possibility of interruptions or faults (e.g. loss of synchronism) on a data link. These safeguards were defined after detailed studies and non-stop discussions between 1965 and 1968, and resulted in a wealth of arrangements of all kinds (of a technical as well as a network management nature) to ensure multiple redundancy of alternate and stand-by data links assigned to different routes.

4.2. The study of the data link network used as common channels for signaling established concepts which were still unheard of at that time but which have now become quite traditional. One

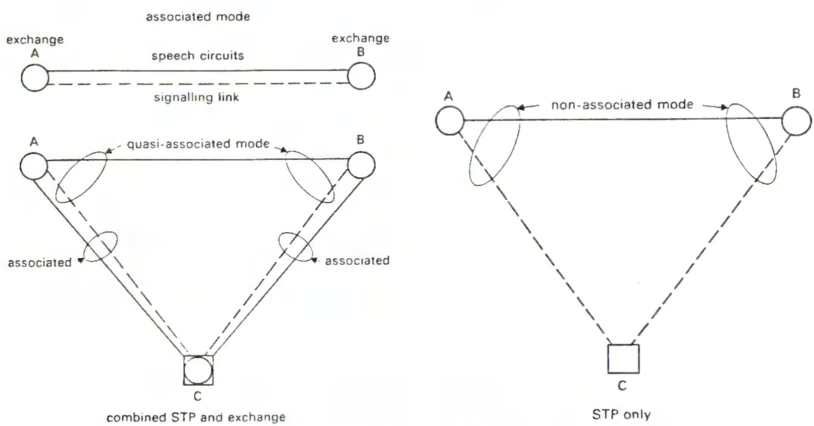

Fig. 2. Associated and non-associated modes operation of signaling links

Box C

CCITT definitions of the associated, non-associated and quasi-associated modes of signaling

In the *associated mode*, the messages relating to a particular signaling relation between two adjacent signaling points are conveyed over a link set directly interconnecting those signaling points.

In the *non-associated mode*, the messages relating to a particular signaling relation are conveyed over two or more sets in tandem passing through one or more signaling points (Signal Transfer Points = STPs) other than those which are the origin and the destination of the messages.

The *quasi-associated mode* is a limited case of the non-associated mode where the path taken by a message through the signaling network is predetermined and, at a given point in time, fixed.

such occasion was the meeting of a Working party in Stockholm in 1967. On a French proposal by P. Lucas, three fundamental concepts were defined for the paths followed by the data link and by the group of circuits covered by the data link. These three concepts are:

- associated signaling
- non-associated signaling
- quasi-associated signaling.

Fig. 2 and the definitions in Box C show what each of these three topological structures signifies.

4.3. In connection with these three concepts, the notion of "signal transfer point" made its appearance. The term which was immediately accepted and officialized, and especially its acronym "STP", came into general use after 1975 and is now universally known. The non-associated and quasi-associated structures were shown at once to be specially suitable for use with small telephone circuit groups. A single signaling channel could be used not only for one group of circuits, but for several. The experts also began to glimpse at all the possibilities which could be offered in future by dissociating the signaling network and the telephone circuit network. For instance, in the context of the North American network after 1980:

- the advantage of seizing the circuits of a connection to set up the speech path of a call only after ascertaining that the call wil be successful (called number not engaged);
- if the called number is engaged, the call could be set up by the incoming SPC exchange, as soon as the called number is free, thanks to an exchange of signaling messages to that effect between the calling and called ends; etc.

5. Other new features introduced within System No. 6

Many other equally novel features, apart from those described above, were also introduced into the specifications of System No. 6.

5.1. A first provision was aimed at preventing a major inconvenience for the operation of circuits, which could arise from the dissociation of signaling from the speech channel. The transmission quality of this channel might be poor, even though the requested call establisment had been successful. Such a situation was altogether unacceptable, since the caller would be paying for an inaudible call. The speech circuit used, therefore, had to be tested beforehand, with a "speech path continuity check", before the called number replied.

5.2. A second provision was aimed at increasing the reliability of the system. In the studies of Study Group XI, reliability was in fact the major leitmotiv during all discussions at its meetings.

To take account of "long burst errors", a data carrier failure detector was introduced to supplement the error correction of signal messages. High error rates introduce delays in the signal transmission because faulty signals must be retransmitted, increasing the load on the signaling link. In such a case, a signal unit error rate monitor recognizes unacceptably high per-

centages of incorrectly received signal units and, when specified thresholds are exceeded, causes a procedure of changeover to a stand-by signaling link.

5.3. A third provision, initiated by the Japanese, aimed at checking whether the telephone signals interpreted by the incoming processor appeared coherent with what their sequence might be. "Reasonableness tables" were established to determine an analysis logic and, where necessary, the rejection of telephone signals. This provision was introduced for cases where, in the event of errors in some signals which were then retransmitted, the normal sequence of telephone signals was not respected.

5.4. Problems concerning the time delays required for a high quality telephone service had led to the solution of some delicate teletraffic problems. The situations involved queues ahead of the data link, with problems depending on both:

– the queues facing the circuits fed by the link,
– the queues of messages for a call.

The theoretical calculations determining these time delays in queuing situations were thoroughly checked during the field trial tests (section 6), showing that the observations made matched the theory perfectly.

6. Field Trials (1969–1972) of System No. 6

6.1. The preceding sections gave a lengthy description of the design work which went into System No. 6, the first common signaling channel system in the world, in the period 1965–1968. Section 6 gives much briefer coverage to the period of its field trials between 1969 and 1972. It is not that the efforts and interest devoted to the system were diminishing at the time. Quite on the contrary... The CCITT study period 1969–1972 was one of intense activity for the system.

We shall not dwell too long on the field trials themselves, since their organization was essentially a matter of logistics, carefully planned and energetically implemented in all its details by the partner countries. To ensure that deadlines were respected, this large-scale project was conducted like a military operation. Even the terminology used, such as the use of the term of "polygons" to denominate the trial networks, was to some extent reminiscent of this miltary analogy.

6.2. Eleven entities (see Table 2) in nine countries (with two entities each for Australia and Italy) took part in the trials. These were conducted on an intercontinental scale. Fig. 3, taken from [3] and presented in a somewhat different

Table 1
System No. 6 field trial partners

Country	Entity	Field trial site
Australia	Post Office Overseas Telecommunications Commission (Australia) – OCT(A)	Melbourne Sydney
Belgium	Régie des télégraphes et des téléphones (RTT)	Brussels
France	Administration des PTT	Paris
Germany (Fed. Rep. of)	Deutsche Bundespost	Frankfurt-am-Main
Italy	Azienda di Stato per i Servizi Telefonici (ASST) Italcable	Milan Rome
Japan	Kokusai Denshin Denwa Co., Ltd. (KDD)	Tokyo
Netherlands	Administration of PTT (Dr. Neher Laboratory)	Leidschendam
United Kingdom	General Post Office	London
United States	AT & T (Bell Laboratories)	Columbus (Ohio)

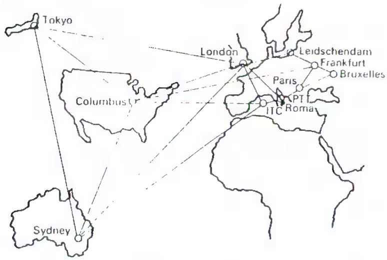

Fig. 3. CCITT System No. 6 Total field trial network

form compared with the more common versions centered on Europe or the Atlantic Ocean, shows how much was contributed to the trials by the countries bordering on the Pacific Ocean.

6.3. The objectives of the trials were two-fold:

a) to check the interworking of terminal installations, which included a great diversity of equipment set up according to the 1968 specifications; to resolve any difficulties arising from different interpretations of the specifications; to compare observed data with the results of previous, pure theoretical calculations, and above all to check the reliability of the system and the associated arrangements;

b) if necessary, and as a consequence of the observed results, to revise certain clauses of the specifications before the latter became final in 1972.

6.4. The trials were directed by a Working Party, drawn from two CCITT Study Groups, Study Group XI and a Study Group XIII (the latter in charge of international automatic telephone networks and dissolved in 1972). This Joint Working Party was competently, authoritatively and energetically chaired by J.J. Bernard (Netherlands).

6.5. Deleting details, we shall merely mention two aspects, the first being an anecdote, and the second of potential interest to national authorities Members of the ITU.

6.6. We have commented already on the work which went into planning and preparing the trials. The task of coordinating them, as much on a national as on an international level, required a real military-style high command, which poured out innumerable standardized forms and documents, such as schedules for the completion of terminal installations, schedules of international measurement dates and tables of recorded data, etc.

Among all these documents, the author remembers a splendid table showing the time gaps available for measurements, when working days coincided in all the partner countries. The summer (on the Western calendar) is dotted with so many public and traditional holidays, differing from country to country, that there were very few working days left in common. With further constraints arising from local time differences, the teams working on trial measurements in the different countries often had to relinquish fond thoughts of the public holidays to which they were entitled!...

6.7. Far more important was the financial evaluation of the total cost incurred for the "Field Trial" operation by all the participating countries. A "report on the trials" was to be submitted to the 1972 CCITT Plenary Assembly. It had been suggested that, instead of drafting the report according to the usual administrative pattern, with its generally boring style, it would be preferable to break new ground and submit it in the more sober but financially well documented form of a "company report". In order to emphasize the magnitude of the accomplished effort, one section of the report was to mention the total cost of the operation, with each partner supplying an individual estimate. The total turned out to be so impressive that some of the partners asked to have these estimates removed from the report, in case it should cause them trouble, for instance with their Ministry of Finance, and it was so decided.

Although it had been thus relegated to a quiet burial in the CCITT archives, the evaluation did re-emerge in 1974 in a rather more elegant and diplomatic form, unfortunately in a form which

was too succinct and too allusive and which passed unnoticed.. In this respect, Raymond Croze, Director of the CCITT, declared in an a leader article of the ITU "Telecommunication Journal" that the amount spent on the trials had been several times greater than the annual budget of the ITU.

Referring as it does to an estimate based for once on such a concrete and well-defined case, this opinion is significant and deserves to be noted, especially by administrative and governmental authorities who, in some countries, may cast doubts on the value of their participation in the ITU.

6.8. After these digressions, let us just mention the main conclusions drawn from the trials:
- System No. 6 had all the characteristics of reliability which had been defined as one of its objectives;
- only a few minor changes had to be made to the 1968 specifications for the final 1972 version;
- the system was perfectly adapted to the best technology of its time and could offer a broad range of new possibilities for the automatic operation of a national or international automatic network.

6.9. Apart from the special issue of the Telecommunication Journal on System No. 6 [1] which includes articles by 23 authors from the nine trial partner countries, a great number of articles were devoted to the system and to its trials, especially in the leading technical reviews of all the partner countries. A bibliography listing the articles which had appeared by 1974 is given at the end of [1].

6.10. Alongside the trial of the system equipment in various countries, a considerable effort to improve the specifications of System No. 6 was undertaken during the CCITT study period 1969–1972 by Study Group XI. The latter defined a different method for the system's data link. Instead of a *link* operating with modems at each end of an analog telephone circuit, a new mode was introduced in the specifications, which consisted in using a *digital* channel of a CCITT standard PCM multiplex.

7. Introduction of system No. 6 after 1974. only A moderate success

7.1. A national telephone network involves a huge deployment of equipment of all kinds, which is very hierarchically ordered:
- at the base, local distribution networks with their cables and cabinets;
- the exchanges, from local switching to national or international transit;
- trunk transmission routes, with coaxial cables, radio-relay links and even satellites.

This deployment can be easily compared to that of armies in the field: the infantry at ground level, the artillery and its weaponry, etc. If the metaphor were to be taken further, what part would signaling play? Undoubtedly, it could be compared with the cavalry leading the vanguard. Signaling is always ready to set off on the road to adventure, to prance ahead and to establish contact with the partners...

Will its spirit of adventure be followed by the main body of the troops? Will its technological breakthroughs be fully exploited? All too often, this has not been and will not be the case. The central command post will remain reluctant before what they consider to be too costly investments, the absence of which will in any case be no source of major difficulties for the public.

7.2. Such is the conclusion which has to be drawn from the lack of enthusiasm which System No. 6 met with when the time came to bring it into service. Once the concert of praises about the system had died away, with its proliferation of articles in leading technical reviews lauding its merits and its novelty and the praiseworthy attitude of the CCITT, there was hardly anyone left to actually put the system into practice.

There was however one notable and highly significant exception, the use of the system in the United States in the form of a national, only slightly modified, version of the international CCITT system. This version, known as "Common Channel Interoffice Signaling" (CCIS), brought about a complete reform of signaling facilities in the North American long- distance network from 1976 onwards.

8. The CCIS system, United States version of System No. 6 [6,7]

8.1. In the United States, the advantages of a common channel signaling (CCS)-type system like System No. 6 had been duly recognized due to:

- its economic aspect;
- the wealth of its signal code;
- its speed, which could offer subscribers in the United States a post-dialing delay of a mere 2 or 3 seconds, instead of the previous 12 seconds average.

International trials of System No. 6 had convincingly demonstrated its reliability, a reliability which could be expected to be even greater inside a national network placed under single, firm management...

The engineers of Bell Laboratories who had taken a very active part in the design of System No. 6 and the staff of Bell Laboratories in Columbus (Ohio), which had served as a base for system trials in the United States, were convinced of its value.

8.2. This interest was shared by the top management of AT&T. Detailed studies,in particular about the economic value of introducing a CCS-system in the American long-distance network, were undertaken straightaway. They were conducted in Bell Laboratories under the leadership of a great proponent of CCS, W.O. Fleckenstein, in conjunction with AT&T's Long Lines. The decision to adopt System No. 6 with slight modifications was taken. An ambitious plan was established. It was to bring about radical changes in long-distance signaling in the United States. The latter, with its MFC signaling sets and its "SF1 system" was over 20 years old and considered to have been somewhat overtaken by recent advances in data transmission technology. MFC signaling sets were relatively costly and, to meet the requirements of traffic growth and therefore of the long-distance network, over a hundred thousand had to be produced each year. This was one of the prime economic benefits offered by CCS.

8.3. The signaling plan for the United States network laid down in 1974 called for establishing 10 signaling regions, coinciding with the 10 long distance switching regions. Each of the signaling regions was to be provided with two signal transfer points (STP), located in two different cities. All STPs were to be fully interconnected with signaling data links.

For the implementation of the plan, one factor in AT&T's favour was the recent massive distribution over its long distance network of *4A-ETS* transit centers. In this 4A-type of exchange, which had first appeared in 1969, an electronic translator system (ETS) was grafted on to a crossbar exchange, which then operated like an SPC exchange. Although these centers, located at the major nodes of the network, accounted for only 10% of all long distance centers, they handled over 50% of trunk calls in 1976.

8.4. To adapt to national conditions in the United States, System No. 6 was slightly modified. For instance, the number of bits in labels for circuit identifications was to be adapted because the size of long-distance circuit groups is generally larger in the United States than for those in other countries.

The system took on the name of "Common Channel Interoffice Signaling" and became more generally known by its abbreviation CCIS.

8.5. In the best AT&T tradition, once the decision had been taken to adopt the CCIS system,

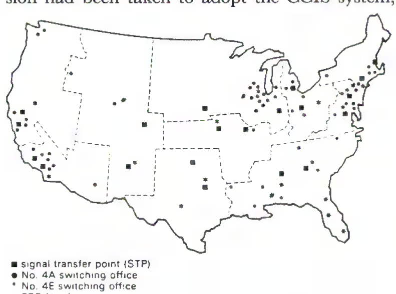

Fig. 4. CCIS implementation in 1979 (from [6], p. 437)

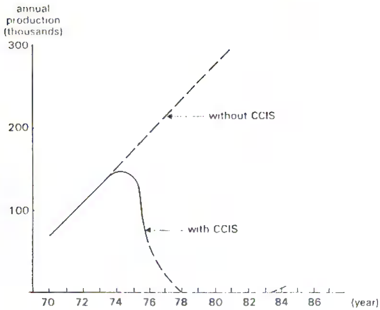

Fig. 5. AT&T study showing fall-off in need for single-frequency in-band signaling equipment as a result of CCIS (from [6], p. 324)

things moved very fast. Implementation of the CCIS system began in 1976. By the end of 1977, all 10 signaling regions were activated. Fig. 4 shows the extent of its application by the end of 1979. Fig. 5 shows the impact produced by the introduction of CCIS on the production of MFC signaling sets by Western Electric for the AT&T long-distance network.

As soon as they began to use the CCIS network, the Americans discovered all the possibilities such a network has to offer. Stored program control was henceforth to be applied not just to one exchange but to the whole of the huge long-distance network of the United States [8]: "the network of the future" was taking shape" [9] (see Chapter X-6).

9. Outside the United States, few very limited attempts at national versions of System No. 6

9.1. Japan had taken a particularly active part in the studies for System No. 6 and, later, during its trials.

Having recognized the full economic benefit to be derived from a CCS system for a telephone network, Japan had very early on undertaken active research and development studies on that type of system:

- studies into SPC switching had not begun in Japan until 1964,
- yet, by 1966 studies were already starting on the CCS system.

For anyone taking a bird's eye view of the movements of technological change, one of the most characteristic elements of the dynamism of an organization or country is the reaction time required to commit itself resolutely to a new unprecedented direction. In this respect, the chronology of the two dates quoted above is exemplary.

9.2. The Japanese studies often produced significant contributions to the preparation of System No. 6 specifications, such as the "reasonableness tables". By July 1967, as we mentioned earlier, the NTT had already been able to set up a laboratory mock-up of the system and to demonstrate it to participants at the Study Group XI meeting in Tokyo.

9.3. In view of the interest which System No. 6 aroused in Japan, it is hardly surprising that very soon a national version of the system was produced for use on heavy traffic trunk routes.

After a series of commercial and real traffic trials in 1972, the Japanese version of System No. 6 was brought into service between the D-10 type toll exchanges of Tokyo and Osaka, which were among the very first SPC exchanges in Japan, those of the standardized D-10 series. In 1977, five D-10 exchanges were linked up to System No. 6 with a quasi-associated type of signaling network [10,11].

9.4. In technology, however, the wheel of progress turns very fast. By 1975, a fundamental re-evaluation of the national network developpment policy was being undertaken in Japan:

- the decision was taken to continue the introduction of SPC exchanges, of the standardized D-10 or D-20 type, on a large scale, so that by 1978 over 200 such exchanges were already operating;

- the increasingly marked trend towards digital techniques, in transmission and later in switching, was observed and duly noted.

In these conditions, NTT found it preferable to defer generalizing a No. 6 type CCS system and to wait for the definition of a system which was starting to be talked about seriously in the CCITT and which was eventually to become System No. 7. This put an end to the spread of the national version of System No. 6 in Japan.

9.5. In all other countries apart from the United States and Japan, and even among System No. 6 sponsors and trial partners, a wait-and-see policy became the rule, as all too often tends to happen after the conclusion of international deliberations!...

9.6. In *Australia*, the only other exception amid this general indifference, it was still debated for a time whether to install a national version of the system. The length of trunk circuits in the country is often of the same order of magnitude as that of intercontinental circuits. This might have provided additional economic motivation for the use of a CCS system. As long as System No. 6 was not in widespread use in the world, however, and as long as equipment manufacturers were offered only a very localized and hence limited market for the system, the latter could hardly prove competitive in terms of price in one country only, which, even though it covered large distances, had only a relative modest population.

9.7. In *Europe*, the impact of System No. 6 specifications was absolutely nil as far as any implementation was concerned, the effect being the same even at the planning level.. There are many reasons which explain the total indifference to the system in Europe:

- in the first place the fact that in the 1970s SPC exchanges were very rare in Europe, whereas by its nature the CCS system implies the existence of SPC exchanges and the more of these there are, the more viable it becomes;
- the supporters of System No. 6 had always been a small minority within their administrations. They usually represented research departments and although their work was undoubtedly and very politely given due recognition, the authorities responsible for operating the networks or taking the decisions were much less motivated. Each country had its own national signaling system and was in no hurry to change it;
- in the national network of a European country, the dimensions, such as circuit lengths and traffic flows on trunk routes, were very different from those of an intercontinental service or those applying to the North American network.

9.8. To keep the record straight, however, it is worth mentioning two exceptions to the general rule of abstention in Europe regarding the introduction of national versions of System No. 6, even though these exceptions were only of very minor importance.

9.8.1. In Denmark, Jydsk Telefon AS, the regional company licensed to operate telephones in Jutland, cooperated with the Swedish company L.M. Ericsson to carry out field trials of System No. 6 in an urban network (Aarhus) between 1974 and 1976 [12].

L.M. Ericsson had taken part, even though only indirectly, in the field trials of System No. 6, having built the international transit center for the OTC(A) in Sydney, one of the terminals of the System 6 trial polygons. The Aarhus exchanges were crossbar exchanges which had been recently modernized and converted into SPC exchanges by grafting duplicated processors onto their architecture. The latter provided an opportunity to test System No. 6 in the field and to assess its technical (signaling time in particular) and financial advantages compared with traditional DC interexchange signaling or the more recent MFC register signaling.

The conclusions of these trials showed:

- once again, the likely value of CCS in the future, even though, in local service, the signaling times with System No. 6 had not turned out to be markedly less than those encountered with the other two compared signaling modes;
- the advantage, to obtain a CCS data link, of using a 64 kbit/s digital channel of a PCM multiplex; signaling speed would be increased and analog modems could be dispensed with.

9.8.2. Although it had given up its original plan of introducing System No. 6 in its analog stored program exchange network, Belgium used this System to transfer charging information to centralized billing centers. Thus a first exchange was commissioned in 1975 and, in 1985, more than 300 No. 6-type data links were still in use in three of these billing centers.

10. Lack of success of System No. 6 on international links within Europe

The use of System No. 6 on international European routes could have been envisaged in view of the dimensions of the network. In fact, the possibility was not even studied. No signaling installation is viable unless it fits into a coherent system decided upon by a group of associated partners. Any such decision is impossible as long as there is no deciding authority. Moreover, in 1968 the European countries had gone in for MFC signaling provided by the R2 System officialized in Mar del Plata. During terminal equipment installation, they were already having difficulties installing this system with proper coordination between the plans of various countries. The idea of introducing a second system in competition with the R2 System on a European scale was therefore out of the question, for very many years to come.

Might there possibly have been, on the part of some of the system's detractors, a psychological reaction – attributable to what has been called the famous "NIH" (Not invented here) effect – which led to dubbing System No. 6 an "American system?" This is no more than idle gossip, unjustified in view, as we have seen, of the amount contributed to the design of the system by the different research partners...

These are the reasons of various kinds which can be put forward to explain the system's lack of success. In fact, the real reason for the indifference which greeted System No. 6 was the one already mentioned earlier concerning the reversal of policy which occurred in Japan between 1975 and 1979: the increasingly rapid pace of technological change. This tilted the scales in favor of digital techniques and encouraged the search for a new CCS System No. 7 designed to operate in a totally digital environment.

11. Introduction of System No. 6 on intercontinental links as from 1978

11.1. International switching centers are monuments, sanctuaries of telephony. There, the dearest commodity in telecommunications – international and intercontinental calls – is handled with infinite care. Acting as it does as a concentration point for this type of traffic for a whole country (or in a few exceptional cases for one vast region of a single country such as the United States), an international center is unique within the telecommunication organization, which tends to look upon these centers as "sacred cows" reserved for the initiated few.

To handle international/intercontinental traffic, the most sophisticated equipment currently available will be used.

11.2. In the first place, this equipment has to be housed. With the explosive annual rate of growth of international traffic – of the order of 20 to 30% – in the 1960s and 1970s, the premises of international centers continually proved to be too limited. Extending them was and still is laborious, complicated and costly, since for historical reasons they tend to be situated in the heart of a capital's business area, precisely where land is most crowded and expensive. Another possible solution is to split the main center into two or more centers, often located outside the capital itself. This alternative, however, means building a tentacular network to provide access and to interconnect the separate international centers.

These civil engineering operations of course take a considerable amount of time, even when they have been planned long in advance, based on traffic growth predictions which are sometimes unfortunately overtaken by events.

11.3. More delays, of the same order, accompany the introduction of a signaling system which is different from those traditionally used on international/intercontinental circuits. In an international center, it would not be worth installing special terminal equipment to handle a single traffic route. Hence the need for a general plan, which is coherent and implies concerted action [1)]

[1)] This role is theoretically vested in the CCIR/CCITT Plan Committee of the ITU (World Plan Committee and Regional Plan Committees), which meet every four years. In fact these committees supervise rather than take decisions. Discussions concerning decisions take place directly between the partners concerned, on a practically continuous basis.

by many countries, which then have to take appropriate decisions to ensure that the introduction of terminal equipment in all the countries is reasonably synchronized.

These discussions obviously delay the project still further. All international telecommunication authorities are fully aware of the fact that *the time needed for an international project is generally twice as long as for a national project*.

11.4. The first intercontinental link on which System No. 6 was used was between New York, Tokyo and Sydney and the new service was inaugurated on July 17, 1987 [13]. The three international centers concerned were:

- in New York, at AT & T's impressive quarters at 24 Broadway, familiar to many foreign delegates (including those of the CCITT), where the first international ESS No. 4 digital type SPC center had just been brought into service a month earlier;
- in Sydney, OTC(A);
- in Tokyo, at KDD.

11.5. System No. 6 was introduced into transatlantic commercial service the following year with the commissioning in London of the United Kingdom's third international switching center, known as "Thames", specialized in intercontinental traffic [14].

The expansion of intercontinental links using System No. 6 continued throughout the 1980s. In 1985 a census of international centers equipped with System No. 6 carried out by the CCIR/CCITT World Plan Committee meeting in Washington (DC) produced the following list:

- Auckland (New Zealand)
- Frankfurt-am-Main (Fed. Rep. of Germany)
- London (United Kingdom)
- Milan (Italy)
- New York (United States)
- Paris (France)
- Rome (Italy)
- Seoul (Rep. of Korea)
- Singapore
- Sydney (Australia)
- Tokyo (Japan)

11.6. The layperson and even a telecommunication engineer who is not specialized in "international work" may find the time interval excessively long between:

- the start of the gestation period of System No. 6 in 1964;
- the issue of final specifications in 1972;
- the opening of the first links operating the system only at the end of the 1970s and their generalized use – on an intercontinental level only – in the early 1980s.

In fact *international systems are rather like trees or young girls, in that they need a good fifteen years or so to yield their fruit or their attractions. This is a lesson which all telecommunication authorities should bear in mind ...*

11.7. For anyone reading technical reviews or prestigious conference acts, the impression produced is that, in the present world of telecommunications, everything evolves with prodigious rapidity. All too often, however, the reader may be deluded by what are still only ideas for the future. To obtain a more accurate view of the rate at which new developments may be expected, it is essential not to underestimate constraints due to the considerable inertia which is implied, for any change of policy, by the enormous mass of a world network interconnecting over 600 million telephone terminals.

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CHAPTER X-5

BIRTH AND BEGINNINGS OF INTERNATIONAL CCITT SYSTEM No. 7

1. Research on system No. 7 initiated in 1976 and its justification

1.1. Signaling systems are just like motor cars; the years go by and models are superseded. They bring the telecommunication enterprise greater performance and profitability. To the public, whether private or business users, they offer an even wider choice of communication facilities.

Thus, CCITT System No. 6 was followed by System No. 7 which took almost as long to gestate.

1.2. It was at its VIth Plenary Assembly in 1976 that the CCITT officially launched its study of System No. 7, though not without some difficulty.. Having established System No. 6 in detail in 1972, was it really necessary and reasonable – four years later – to start studying a new system that was bound to compete with it?

Some of the reasons for studying a new system have been outlined in Chapter X-4, but the invasion of telecommunications by digital techniques was the main if not the underlying one.

1.3. There was also another reason – both circumstantial and directly linked to CCITT – which would explain why this organ eventually decided to study a new signaling system. Born of the merger in 1956 of its two predecessors, namely the CCIT (telegraphy) and the CCIF (telephony), the CCITT had lived out its first 16 years as a simple juxtaposition of two sets of Study Groups with no close links between them:

- the telegraphy Study Groups which flung themselves headlong into the unexplored but promising territory of data transmission;
- the telephone Study Groups which steadily pursued the traditional course of their own studies.

These two tributaries of the CCITT had not yet reached a confluence and their waters flowed in parallel without meeting.

At the time of the Vth Plenary Assembly (1972) – four years prior to the Plenary Assembly at which it was decided to study System No. 7 – the two mainstreams were finally merging:

- the concept of a common telephone and data carrier network, later known as the integrated services digital network (ISDN), was timidly emerging;
- the research on System No. 6, with the labeling of its telephone signaling message, had revealed certain analogies between that system and data transmission systems, including the packet switched variety which the CCITT and many research centers were just beginning to study;
- the open system interconnection (OSI) methodology, introduced by the International Organization for Standardization (ISO) and quickly adopted by the CCITT data transmission Study Groups, looked as promising in telephone signaling as it was in data communication;
- CCITT research on digital techniques, which from 1965 to 1968 had been confined to transmission system applications within Study Group XV, broke out of that narrow framework at Mar del Plata (IVth Plenary Assembly, 1968). A special Study Group (known as "Special D") was instructed to define the structures of a digital network. Special D was institutionalized at the VIIth Plenary Assem-

bly in 1980 and became known as Study Group XVIII which, under the authoritative and competent chairmanship of T. Irmer [1)] (Fed. Rep. of Germany), was to play a major role within the CCITT, namely that of concerting the work of many Study Groups engaged in both data communications and telephony [1].

1.4. As mentioned, these structural changes in the CCITT were circumstantial compared to its decision to study a new signaling system.

What must be seen beyond these domestic details is that the structure of the CCITT Study Groups accurately reflected the different stages in the swift and radical change that came about in telecommunications during the 1970s. This was a result of technological advances in components, which ushered in a variety of "new services" in telecommunications and gave rise to fast and large development of the computer industry. These advances were to bring about profound modifications in what were once the traditional constraints on the structures of telecommunication enterprises. After lengthy negotiations, the United States policy of AT&T divestiture was officially endorsed in 1983 and now offers the supreme example of these trends.

The ISDN concept is the infant that was conceived to meet these technological and structural changes. As in any other conception, its parents surely had no idea as to the eventual consequences of their act!...

1.5. The ISDN, which was to become the major concern of not only the CCITT but of telecommunications as a whole in the 1980s and possibly also the 1990s, rests in fact on two foundation stones:
- SPC switching which reached the age of maturity in the 1970s;
- CCS signaling which, following the tests on System No. 6, had just completed its technical and reliability trials in 1976.

[1)] elected Director of the CCITT in 1984.

1.6. Two new developments in the mid 1970s led to the decision by the VIth Plenary Assembly (1976) to study System No. 7:
- the introduction of digital switching, particularly in France and Canada, with in the United States the AT&T decision to use this switching mode in the ESS No. 4 intended for its large long-distance or transit exchanges;
- the affirmation of interest in the ISDN concept itself.

2. Features of System No. 7. Its modularity [2–5]

2.1. The "architectural part" of the future system was thus clearly outlined. It was to be a system [2a,3]:
- intended to support a wide range of digitally-based services;
- intended to provide a foundation for ISDN, which was to offer future business and residence telecommunication users a range of voice and non-voice services via a single standardized interface;
- able to meet present and future requirements of information transfer for interprocessor transactions;
- optimized for operation in digital telecommunication networks in conjunction with SPC exchanges;
- optimized for data links operating over 64 kbit/s digital channels;
- suitable for both national and international operation.

2.2. Whereas the designers of System No. 6 had acted as "explorers" so to speak, proceeding in successive stages and gradually mastering the many problems of making the system as reliable as possible, the designers of System No. 7 benefited from all the knowledge and experience gained in working out the tests for its predecessor.

In addition they had a whole set of high-performance technological bridgeheads which had been gained in the eight years between the gesta-

tion of Systems No. 6 and No. 7, the main ones being:
- increased performance in data communications reliability, particularly as a result of high level data control (HLDC) procedures in which the number of bits in a message had no preferential values, and the performance level adopted for CCITT Recommendation X.25;
- the speed of transmission of signaling messages, which rose from 2.4 kbit/s under System No. 6 to 64 kbit/s; – the OSI methodology which was to serve as the reference criterion for defining a functional division for the system.

2.3. The fundamental principle of the System No. 7 structure is its functional division into:
- a common *message transfer part* (MTP);
- separate "*user parts*" (UPs).

The overall function of the MTP is to serve as a transport system providing reliable transfer of signaling messages between the locations of communicating user functions. The term "user" in this context refers to any functional entity that utilizes the transport capability provided by the MTP.

The user parts specified by the CCITT up until 1984 (VIIth Plenary Assembly, Malaga-Torremolinos) were:
- the *telephone user part*
- the *data user part*
- the *ISDN user part* (partially).

This differentiation between MTPs and UPs heralds one of the characteristic features of System No. 7, i.e. its modularity. This concept, since the mid-1970s, had become the key to the architecture of every telecommunication system, whether in signaling, switching or transmission. Modularity in System No. 7 went far beyond the MTP-UP differentiation and was pursued at several levels.

2.4. According to the principles of OSI hierarchical structuring, a four-level structure was adopted for System No. 7 [2a]. This is illustrated in figures 1 and 2 which represent the structure in two different ways.

2.5. The lower levels, i.e. levels 1 to 3, relate to the MTP:
- Level 1 corresponds to the *signaling data link* (Recommendation Q.702), i.e. "a bi-directional transmission path, comprising two data channels operating together in opposite directions at the same data rate." At the basic level, it relates to the physical medium (whether digital or analog) which permits the full-duplex transmission of information;
- Level 2 corresponds to the *signaling link functions* and determines the procedures for ensuring their reliability. Primarily, these are the functions (Recommendation Q.703) of:
  * signal unit delimitation,
  * signal unit alignment,
  * error detection and correction,
  * error monitoring;
- Level 3 corresponds to *signaling network management functions* such as:
  * discrimination which determines according to the signaling point (SP) destination code whether or not the exchange is the destination point of the incoming message,
  * determination of the CCS routing (for originating or transferring messages),
  * distribution of incoming messages for determining to which user part a message has to be delivered,
  * message traffic management (changing to standby channel, return to original channel, activation, restoral, etc.).

(If and when System No. 7 has to be used solely as a point-to point link over one and the same route, the level 3 functions are not needed.)

2.6. Level 4 relates to the UPs. Every UP defines its level 4 functions and procedures of System No. 7 that are particular to its type of system user.

Levels higher than level 4 can be defined by (and for) particular types of users, e.g. for specific private network systems or the transfer of information for management or maintenance purposes. However, these do not come now within the CCITT specifications of System No. 7.

2.7. Anyone who is not a signaling specialist and wants a simple picture of the structures of

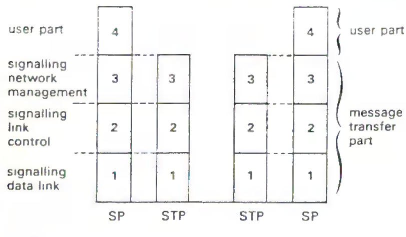

Fig. 1. Hierarchical structure of System No. 7

System No. 7, should try to imagine a railway network:

- the track on which the train runs is the counterpart of the signaling data link (level 1);
- the signaling link functions (level 2) find their counterpart in the signaling devices along the track taken by the train on arriving at a station;
- the signaling network management functions (level 3) represent all shunting within the station;
- the UPs (level 4) are such potential branch-line destinations as passenger stations, goods yards, sorting yards or even another public or private network.

3. Message coding in System No. 7

3.1. The main advantage of System No. 7 over its predecessor, System No. 6, lies in the wealth of signal coding obtainable through its message format. This implies incomparable flexibility as regards the user of the system itself. These two basic characteristics of System No. 7 correspond in all respects to the design objectives established when the system was first studied, i.e. that it should be able to afford a universal multiservices signaling network.

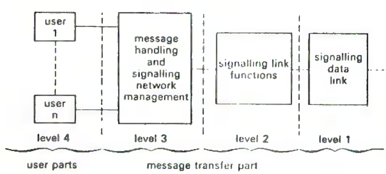

Fig. 2. Functional levels in System No. 7 (only one side of the signaling link is shown, the right-hand side would be symmetrical) (from [4])

3.2. Borrowed from the vocabulary used in the specifications of System No. 6, messages in System No. 7 are known as signal units (SUs).

3.3. Instead of having SUs of a constant bit length as in system No. 6, the format adopted for an SU in System No. 7 is that of a variable (but high) number of octets.

A variable SU length meant that its beginning and end had to be determined, thus requiring an SU alignment method. The indicators for delimiting an SU are the system's characteristic flags [2]. This is an octet with the characteristic format "01111110"; a protection device [3], built into the system's processors prevent this format from being imitated by any SU component that is not a flag. To the designers of System No. 7, the flagging of SUs was a transfusion of advances made in data communications. In 1976 a similar method had just been specified for packet switched transmissions in what is perhaps the most celebrated of all CCITT Recommendations, namely X.25 [4].

[2] In connection with the French vocabulary of System No. 7, it is amusing to note that, initially, the French term for flag was "drapeau" but, for the sake of keeping the same abbreviations in French and English, this was replaced by the term "fanion".

[3] To avoid the flag code being imitated by any other part of signal units, a stuffing mechanism in the transmitting signaling link terminal inserts a "0" after every sequence of five consecutive "1" before the flags are attached and the signal unit is transmitted. At the receiving signaling link terminal, after flag detection, each "0" which in the signal unit follows a sequence of five consecutives "1" is deleted.

[4] X.25 has become a universally known acronym throughout the data communications world although most of its users are completely unaware that its denomination is simply the serial number of a CCITT Recommendation.

The lengthwise variable content of the message to a UP is thus inserted between two flags. The SU format enables a UP message consisting of a whole number of octets to be transmitted, as many as up to 60, though for special national applications it may even be increased to the upper limit of 256 octets.

3.4. Besides the information in the message to a UP (which makes up the signaling information field), eight fixed-length fields which contain the information required for error control and message alignment are inserted between the two opening and closing flags, the closing flag often being the start of the flag for the next SU. Of these eight fields, the *main ones* are:

a) the "length indicator" field indicating the number of octets in the SU;
b) the "sequence numbering" field giving the forward sequence number of the SU in which it is carried and the backward sequence number of an SU being acknowledged;
c) the 16 bits of the "check-bit field" for error detection.

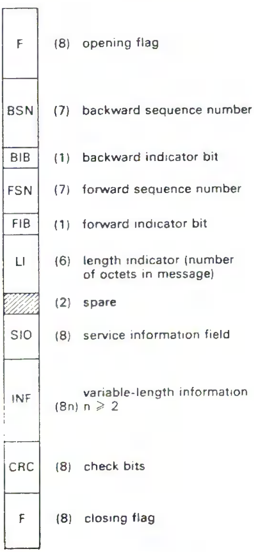

Fig. 3. The variable-length format of a System No. 7 signaling unit (SU)

Fig. 3 gives a more detailed description of the format of a System No. 7 SU.

3.5. Furthermore, the message to the UP is labeled, though within the signaling information field since the message falls within structural level 4, i.e. the rules relating to a given UP. However, a fraction of the label also enables the MTP to route the message towards its destination point. This fraction, known as the *routing label*, consists of 32 bits indicating inter alia the codes of the message destination and originating points.

There is a notable difference between labeling in Systems Nos.7 and 6. In the latter the message destination point is implicitly indicated: this enables the content (and therefore the length) of the signal unit to be shortened, and this is a method more closely fitted to use in associated signaling. In System No. 7, the destination point is explicitly indicated, as authorized by the available length of an SU: this method, more closely fitted to use in quasi-associated signaling, facilitates label translation in signaling transfer points (STPs) and is also suited for carrying signals that are not associated with a particular circuit [3].

4. Availability and reliability

4.1. As the name suggests, the 16 bits in the error detection field simply detect errors in the bits transmitted. As in System No. 6, error correction is ensured by requesting the retransmission of an erroneous SU. Hence, the need for storing at the originating end SUs that have not yet been correctly acknowledged, and for the sequential numbering of the SUs transmitted. As indicated in paragraph 3.4b), the SUs are numbered by one of their own special fields.

The bit error detection system of a signaling data link is provided by a polynomial device identical to that used for packet switched data transmission. Here, we have another example of

the technology to which the designers of System No. 7 had immediate access. In both packet switched transmission and System No. 7, the standardization of common provisions relating to flag constitution and error detection offers a substantial economic advantage in being conducive to the larger-scale production of the LSI components used for carrying out the logical operations required by the provisions themselves.

4.2. The automatic correction of incoming bit errors was a feasible conventional method but would have involved a check-bit sequence of inordinate length. As in System No. 6, therefore, the acknowledgement method for triggering the retransmission of erroneous messages was again adopted.

Determination of the erroneous message retransmission mode was the subject of lengthy discussions within the CCITT. Eventually, to allow for major differences in the propagation time of a signaling data link depending on the transmission media used, two erroneous SU correction methods were defined:

- *the basic* one, intended primarily for terrestrial links with one-way propagation delays of up to approximately 15 milliseconds;
- *the preventive cyclic retransmission method* for links with high propagation delays (e.g. satellite or very long terrestrial circuits), for which the transfer time for obtaining retransmission of erroneous messages would be prohibitive.

Both methods are non-compelled. The first uses positive and negative acknowledgments. The second uses only positive acknowledgments but all unacknowledged messages are cyclically retransmitted whenever there are no new messages to be sent.

A detailed description of the intricacies of the two methods is given in [2 and 4].

4.3. The error detecting and correcting processes provide for reliable message transfer under normal transmission conditions for the signaling data link. In System No. 7, as in No. 6, and with the same type of device, *permanent monitoring of the SU error rate* on a signaling link is carried out. It provides one of the criteria for taking the link out of service when the SU error rate is too high. Denominated in Study Group XI signaling jargon "the leaky bucket", the device is an up-down counter, decremented at a fixed rate, for received SUs and incremented every time an SU error is detected. A threshold level of the counter provides the link failure indication.

4.4. The provisions described above relate to a particular signaling link and thus should fall into level 2. However, the command, triggered by the "leaky bucket", for putting a link out of service and moving to another link is given at level 3 used for signaling network management.

4.5. As in System No. 6, and in fact simply transposed from No. 6 to No. 7, there is a whole panoply of provisions for ensuring permanent service in the event of a signaling link becoming faulty. The innovation of introducing a "hierarchical structure" for System No. 7 enables us to pinpoint these functions as *level 3 signaling network management* functions.

A first safeguard is provided by duplicating the signaling links, operating in parallel and preferably on a load-sharing basis.

Other safeguards derive from the existence of immediately accessible first-reserve paths or second-reserve paths obtained by assigning a circuit (or one of a group of circuits) for priority use as such. The change-over, change-back and signaling link activation and restoration procedures are described in detail in Recommendation Q.703 where they occupy no less than 86 pages!...

When all direct links between two points are faulty, a third safeguard – also mentioned in those pages – involves transferring messages via a third signaling point, i.e. a STP.

4.6. The foregoing considerations all reveal the major importance of the constitution and meshing of the System No. 7 network in order to take full advantage of the System.

National use of System No. 7 requires a long-term overall plan that can be worked out in stages to determine the respective role of SPs and STPs, their location and the number of signaling links between them, including reserve links, etc.

The same will obviously apply at the international level, with all its attendant difficulties resulting from the lack of any hierarchical decision-making authority and of the consequent need for prior agreement between the telecommunication authorities of the different countries. On the other hand, the cost of international/intercontinental communications is conducive to the earliest possible introduction of a high-performance system capable of providing both telephone and data transmission signaling from 1985 onwards. The first transoceanic fiber-optic submarine cable linking Japan and the United States was to provide the first opportunity for using System No. 7 for intercontinental or even international signaling.

4.7. Network management imply traffic studies. The teletraffic studies on System No. 7 had to determine the admissible load (expressed in signal units) of signaling links and, more difficult still, the queuing times likely to be caused by erroneous SU retransmission methods. These studies were delicate, particularly since many basic parameters could be only roughly estimated owing to the possible diversity of UPs, some of them having still unfamiliar characteristics. International tests conducted on the MTP of System No. 7 in 1982 and 1983 confirmed that the calculations made were fully valid.

5. The telephone user part

5.1. The telephone user part (TUP) is intended to serve one of the most – if not by far the most – important users of System No. 7.

It is the only user part that we shall describe in this book, since far more space would be required to describe the provisions relating to the data user part and the ISDN user part alone. System No. 7 can be used both at the national level (many codes available in reserve for specifically national telephone signals) and at the international/intercontinental level. System No. 7 enables all types of telephone circuits to be served, whether they be:
- analog or digital,
- terrestrial or satellite,
- as in the case of many intercontinental circuits, equipped with TASI-type (time-assigned speech interpolation) systems.

5.2. The list of international TUP telephone signals included all those listed in the specifications of System No. 6, plus a fairly considerable number of others, and leaves a wide reserve margin for offering telephony any other type of signals imaginable.

The coding of each signal is given in Recommendation Q.723 [Volume VI, fascicle VI.6, of the CCITT Book, Yellow (1980), Red (1984), Blue (1988), etc.!]. It also contains the provisions relating to the transmission speed of the called party's address. The provisions mention two types of possible address signal transmission, namely:
- "en bloc" operation,
- "overlap" operation,

and describe the arrangements for releasing the connection and, if necessary, carrying out prior continuity checks.

These are all completely conventional provisions and, for the most part, repeat those defined in the specifications of System No. 6.

5.3. The levels of the operational performance expected of System No. 7 (Recommendation Q.725) were rather novel and an improvement over those of System No. 6. For instance:
- the proportion of calls that are unsuccessful due to signaling malfunction: less than 1 in 10^5;
- the unavailability of a signaling route set: not to exceed a total of 10 minutes per year;
- the values of cross-office transfer time, retransmissions inclusive: not more than 1 in 10^4 signals delayed more than 300 ms, as a long-term average.

5.4. Far more tangibly, System No. 7 will offer subscribers many advantages such as:
- considerably reduced post dialing delays, which will be of the order of 1 second;
- a greater range of facilities. In the case of a subscriber being temporarily transferred to another call number, for example, the connection circuits will only be seized after the trans-

fer number has been obtained from the called party's exchange. Appropriate charging arrangements may also be made if the normal number and the transfer number are not in the same charging areas;
- ability to exchange messages during the call phase;
- easy identification of the origin of malicious calls, (though it may be hoped that the facility will not be used excessively for police monitoring ...);
- etc.

5.5. Quite apart from being able to use a common signaling network for telecommunication modes other than telephony, telecommunication enterprises will experience a sharp increase in their operational efficiency. With the signaling network management of the speech network, the number of unsuccessful calls due to congestion in traffic routes or at transit centers will be substantially reduced by use of alternate routing and the decrease of repeated call attempts. Selecting only after it has been ascertained through signaling that the called party is not engaged will also save vital speech circuit occupancy time taken up by unsuccessful calls.

6. Genesis of System No. 7

6.1. This description of No. 7 has enabled to follow step by step each basic feature of its architecture, namely, the inputs and "building blocks" which its designers found already available for use:
- from data transmission technology
- from System No. 6, its predecessor.

6.2. Once its general architecture had been designed, the System was logically constructed in an appropriately modular fashion.

First came the most difficult part of the specifications, namely the definition of the clauses relating to the MTP, a part which alone comprised three hierarchical structure levels. As a common trunk for an open-ended number of services, full account had to be taken of all known or foreseeable constraints affecting each and every service. Research departments in the countries participating in the development of the system made numerous teletraffic calculations and carried out many studies for defining erroneous signal unit retransmission methods. Numerous working meetings on the subject had to be held.

6.3. The definition of the MTP and the TUP came within the competence of CCITT Study Group XI. Their specifications and, initially, the basic architectural principles of System No. 7 itself, were prepared by one of its Working Parties, which, under the authoritative chairmanship of P. Plehiers (Belgium), proved extremely active.

The clauses relating to the data user part (DUP) were the responsibility of Study Group VII (Data communication networks) chaired by V.C. MacDonald (Canada).

6.4. This work took up no less than two CCITT "study periods", i.e. the eight years from 1976 to 1984. However, by 1980 the bulk of the clauses for System No. 7 had been defined and Volume VI, fascicle VI.6, of the CCITT Yellow Book published after the (1980) VIIth Plenary Assembly, already contained the clauses of the MTP, the TUP and the DUP (data user part), albeit as provisional clauses subject to revision.

6.5. Various national studies were conducted, independently of the CCITT studies on System No. 7, into signaling for specific purposes and they converged with the studies on System No. 7. As an example of such studies, use was made of the CCS principle applied over the digital channel carrier of a PCM system. This was particularly true in the case of an Australian research into the remote control of a remote switching unit attached by a PCM link to its parent exchange [6]. This type of application of System No. 7 will be discussed later.

6.6. Just as it had been deemed necessary to conduct detailed tests on System No. 6 from 1969 to 1972 among the partner countries in its study,

System No. 7 was tested at the initiative of the Chairman of Working Party "Signaling System No. 7", in 1983 and 1984.

However, these tests were not on the scale of those conducted between 1969 and 1972 for System No. 6. Only two pairs of countries:

– Japan-Australia (both Australian Post Office – APO, Melbourne, and the Overseas Telecommunications Commission (Australia) – OTC(A), Sydney), and
– Belgium-United Kingdom conducted tests over international links, thus implying completely different types of terminal equipment at every end. Moreover, these international tests related to the validity of the MTP alone.

Other tests were conducted in the Federal Republic of Germany, France, Japan and Sweden but strictly at the national level. Besides the MTP, some of them also covered the validation of the TUP.

The reports on the tests, as well as those sent to the CCITT of course, were the subject of a special session (31B) of the ISS 84 (Florence, Italy) and constitute an extremely rich and interesting documentation on the operation of System No. 7 [7]. They contained the finest possible tribute to those who had drafted the specifications, reporting that "it was a pleasant surprise" to find, once the equipment had been connected at both ends, namely in Japan and Australia, that the link was in operating order. Verification of the conditions of availability of the signaling link was one of the major objectives of the tests, the results of which exceeded all expectations.

The tests themselves involved a wide variety of links used for carrying the signaling data, with satellite, submarine cable, 12-circuit groups and analog circuits carrying the data with the use of modems.

7. Initial deployment of System No. 7

7.1. As this book goes to press, it is still too early to say how and at what rate System No. 7 will expand in the coming 10 to 20 years.

However, a number of the countries with the largest networks have taken decisions of the utmost importance to the system in pronouncing, some categorically and others taking a longer term view, for the adoption of System No. 7 in their national networks. This was the tenor of the keynote addresses made at the opening of the Florence ISS 84 by senior officials representing Canada, France, the Federal Republic of Germany, Italy, Japan, the United Kingdom and the United States. This list contains only the countries which had the honor of addressing the ISS 84 opening meeting. In addition, many other countries, particularly Sweden, also committed themselves to adopting System No. 7 at the national level.

7.2. At present, there is hardly a telecommunications equipment manufacturer left who is unable to deliver equipment for System No. 7 in 1988 or the very near future.

7.3. As mentioned earlier, the introduction of a system at the international level is always a much slower affair.

At its meeting in Washington, DC, in April 1985, the CCIR/CCITT World Plan Committee of the ITU followed its traditional practice of making an inventory of the types of signaling systems fitted or shortly to be fitted at "international exchanges". Although the list mentioned "Signaling System No. 7" at a number of exchanges, in the main, no expected date/year of introduction was given.

7.4. The first page of the specifications of both Systems No. 6 and No. 7 warns that at the international level "The strict observance of the specifications for standardized *international* signaling and switching equipment is of the utmost importance in the manufacture and operation of the equipment. Hence these specifications are obligatory except where it is explicitly stipulated to the contrary."

7.5. There is far greater freedom to adapt System No. 7 to specific needs at the national level, where a whole series of subfamilies of the System may coexist with the basic system strictly defined

and standardized for signaling over the national network.

For instance, it may be used to serve operators' positions at international exchanges. Operating in an associated point-to-point link between the international exchange and the operator's room does away with the need for MTP level 3 (signaling link management). The same would apply to links between exchanges and a centralized maintenance center. At most, the only thing that might be regretted is that the centralization of maintenance, so popular since the mid 1970s, came into its own before System No. 7 had been finalized; generally speaking, signaling to maintenance centers is in accordance with the CCITT data link protocols, not System No. 7.

7.6. The same applies with regard to signaling between remote switching units (RSUs) and their parent exchanges. The explosion brought about in switching with the ever-increasing use of RSUs is one of the characteristic features of switching in the second half of the 1970s and in the 1980s. Here, too, System No. 7 arrived a little too late and RSU control signaling was usually effected in accordance with such protocols as CCITT LAP-B, not System No. 7. Since 1982, however, there has been some move towards System No. 7 principles, e.g. the reduced CCITT System No. 7 format used for signaling between the RSUs and their parent exchanges of the ITT 1240 system installed in Norway [8].

7.7. System No. 7 principles also exist, particularly in the use of simplified signal unit formats, in a very wide range of applications:

- firstly, as an internal signaling system in the sytem architecture of an exchange, e.g. in those of the British System X,
- for more specific systems, e.g. rural radio systems. These are employed for serving populations scattered over vast territories in desert, arctic or dense forest areas and use radio links to provide primary PCM multiplexing. Signaling from the remote subscriber to the parent exchange is often of a type derived from System No. 7.

7.8. However, System No. 7 is above all a preferential signaling carrier in an ISDN nework environment, having been born exactly on time and specified when it was needed. The essentials of the ISDN user part were defined in 1984 for relations between exchanges.

System No. 7 must be regarded as one of the pillars of any ISDN. Its use will become even more important when the ISDN is generalized in accordance with very generous standards offering the subscriber two 64 kbit/s B channels and one 16 kbit/s signaling D channel at his terminal; and already, in what in some countries has been the IDN (Integrated Digital Network), i.e. a first phase of progression towards the IDSN, when the terminal had access to only one 64 kbit/s B channel but with the possibility of digital connectivity between subscribers.

7.9. The definition of digital line signaling between subscriber and exchange – an essential basis for ISDN implementation – has been the subject of many studies during the first half of the 1980s (see Chapter X-9). Rather than a universal solution for all countries, there will probably be different solutions in each or many country(ies) for implementing digital subscriber lines. Some have been thoroughly and field-trial tested and options have already been taken out by a number of manufacturers and telecommunication enterprises.

Anyone who examines the existing or planned formats and protocols covering signaling over digital subscriber lines cannot fail to remark their descendence from System No. 7 which subtends the principles of this new type of signaling.

7.10. We thus see the emergence of a veritable family tree of digital common channel signaling:

- systems arising initially from System No. 6, their foundation stone,
- amplified and renewed in System No. 7,
- branching out into signaling for the ISDN,
- and, after the necessary transposition, reappearing in digital subscriber line signaling.

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CHAPTER X-6

FROM COMMON CHANNEL SIGNALING TO THE STORED PROGRAM NETWORK

1. Common channel signaling in the era of electronic switching

While, early in the history of switching, an equivalent of common channel signaling (CCS) was used between manual switchboards and their customers, it was not until the advent of electronic switching and data communications that the modern development of CCS could be realized. From a technical standpoint, CCIS requires economical processors in the central office to attain its inherent signaling advantages of speed and flexibility. While there was some examination of the possibility of introducing CCS into electromechanical systems (EMS), they all failed due to the lack of a central electronic processor.

To make CCS as well as new services available in EMS offices electronic stored program controls were added [1]. These were given various names, such as electronic controllers and translators. Microprocessors for these controls became available about the time of the introduction of CCS, helping to insure that this new form of signaling could be introduced economically.

2. Rapid introduction of CCIS into the United States AT&T Network [2]

2.1. The advent of common channel signaling (the American "Common Channel Interoffice Signaling" = CCIS) [1] in AT&Ts domestic long-distance network in the United States coincided with the rapid deployment of the electronic switching in that network. By 1976 almost all of the long-distance network had been equipped with some form of stored program control (SPC) electronic switching. The most popular SPC arrangement was the use of adjuncts, called "electronic translator systems" [3], in more than 150 No. 4 Crossbar long-distance offices. In addition there were about a dozen No. 1 ESS offices. All these represented about 75% of the total network capacity. CCIS was being added to all of these systems and, including the new No. 4 ESSs, about 100,000 new or converted long-distance circuits were served each year.

The CCS chosen initially for the U.S. was a form of CCITT signaling system No. 6. It had to be slightly modified in the format of its "signal units" because the size of American circuit groups in many instances exceeded the limit the CCITT expected in international service. The STP function was performed by using processors from replaced No. 4A crossbar electronic translator system offices.

2.2. The United States is a large country. The deployment of common channel signal was particularly beneficial since many long-distance calls progress through the hierarchy of offices: in each connection, an average of 2.5 long-distance offices were involved.

With multifrequency addressing, call-set-up time (the "Post Dialing Delay") was more than 12–15 seconds as the signaling progressed from office to office. By using CCIS this time ultimately was reduced to about 2 seconds.

2.3. Another factor that affected the desire for introducing CCIS in the United States was the

[1] See section 8 in Chapter X-4

presence of fraud or theft of service due to the growing use of in-band signaling. These signals originated at telephones acoustically coupled to what were called "blue boxes" [4]. These boxes simulated signal-frequency supervisory and multifrequency address signals tones used to and from offices (see Box D in Chapter II-1).

2.4. For long distance applications there were very obvious and definitive economic trades. The single frequency (SF) signaling-sets used on each long-distance circuit and many long-distance connecting trunks, while improved through several generations of design, were costly. CCS eliminated the need for these sets. The economic trade-offs were quite favorable to CCS. With the introduction of CCIS, AT&T practically ceased the productions of SF-sets [2]. (Sets removed due to the use of CCIS were reused for additions to offices not yet equipped for CCIS) [5].

2.5. Besides the obvious advantages of CCS, in the United States additional savings in trunking could be realized by introducing call routing taking advantage of the non-coincidence of busy hours between different time zones. This feature, known as "non-coincident call routing" [6], was eventually introduced. In a more sophisticated form, known as "dynamic non-hierarchical routing", it is the basis for engineering the current AT&T network [7].

2.6. CCS utilization was visualized from the top of the services tree downward. It was natural that its use was first proposed and tested for international service. In the U.S. where the network was large in several respects, similar factors mitigated for the deployment of CCS.

While most long-distance service requires interoffice signaling equipment, the ultimate speed and service advantages accrue when CCS is brought to the local or end offices. Here, however, the economics for change to CCS are more difficult to justify. The only signaling facilities between local offices were wire pairs. Therefore it is necessary to find new revenues to pay for the equipment required for CCS STPs and data links. This has not always been easy in a regulated environment. Generally, proceeding with local CCS depends upon justifying the expenditure as part of overall service improvement.

[2] See Figure 5 in Chapter X-4

3. The Signaling Network

3.1. The rapid conversion of the United States long-distance network to CCS led almost instinctively to attempts to find greater uses for this improved type of signaling.

In the planning for CCS, great care was taken to insure that, besides accomplishing the equivalent of over-the-trunk supervisory and addressing signaling capabilities, there would be features, the lack of which in the past had considerably frustrated network planners. Two of these that were uppermost in the minds of those working on the CCS standards are referred to here.

3.2. So-called "traveling class marks" were seen as desirable so that offices through which a call passed could have knowledge about how it was expected to be treated. Two examples most often used are the following:

3.2.1. By forwarding class of service information about the calling line to the called end of the connection, it would be possible to take unique action on the call. For example, if the call is from a coin telephone, an operator in a distant office would know what coins must be collected before the call could proceed.

3.2.2. If a call passed through an office that selected a circuit routed via a communications satellite, then later offices should not select another satellite circuit, since the sum of the round trip signal delays through more than one satellite circuit gives correlative speech delays which are intolerable (this is a clause of the CCITT Recommendations). By associating this additional piece of information with the call address, selection of another satellite circuit in any succeeding office could be avoided.

3.3. Call Management Services (CMS)

More advanced service possibilities that were envisioned when CCS was fully deployed in local as well as long-distance offices were those using "reverse signaling." Until CCS, the only signal available universally in the reverse direction that could be machine detectable was call answer.

The AT&T planners became quite prolific in proposing many of what they called "call management services" that looked forward to the availability of CCIS down to the local offices. The following are some examples of these:

3.3.1. Look-Ahead-for-Busy. Rather than set up advance connections to the called office, it would be possible to first send a CCIS signal to the called end office to determine if the called line was busy before establishing connections in the intermediate offices. If the line was busy, a CCIS message could be sent to the originating office from which the busy tone would be sent to the caller. This would avoid the normal practice of holding interoffice circuits busy during the time the caller listens to the tone before hanging up. When the called line is found idle, the originating office is signaling that the call set-up can proceed.

3.3.2. Call Tracing. When the called party receives an annoying or threating call he could send a surreptitious signal to his central office. By CCIS a signal would be sent to the offices in reverse order to determine the number of the calling line in its local office.

3.3.3. Selective Call Waiting and Call Transfer, Priority ringing, Reverse Call Charging, Calling Number Display, etc.: All of these refer to information stored in terminating offices about unique services subscribed to by called lines. Most require a preliminary determination of the identification of the calling line service or telephone number. Appropriate signals are sent in the reverse direction to that effect. The originating central office then uses this information to display, ring, or send the number to the caller or to temporarily store it in a data base to be matched against the other information stored there.

As early as 1977 AT&T made extensive marketing studies of these services to ascertain the potential popularity at different charges [8]. The result of this study showed great revenue potential for them.

4. The SPC Network

4.1. Call management services stimulated new ideas about network-wide services much like when custom calling services (abbreviated dialing, etc.) were originally introduced with the first (No. 1 ESS) electronic switching systems. A careful distinction was made between two network concepts. One was the Common Channel Interoffice Signaling Network, the "signaling network", that included all offices equipped with CCIS (circuits and data links), including SPC operator systems (TSPS, see Chapter V-2.6).

The other was called the "SPC Network" [9]. It represented a definitive effort to provide trunking and to route as much traffic as possible between ESS offices equipped with CCIS. As a result it would be possible to plan for the maximum deployment and utilization of the Call Management Service. The SPC network, in effect, is an extension of custom calling services from individual local SPC offices to an entire network of local offices. To accomplish this requires the storing of call routing information.

5. Data-Based Services in SPC Network

5.1. To complete the SPC Network concept a most important additional creative element was added. This invention was made by Roy Weber of Bell Laboratories [10,11]. It consisted of adding access to data bases at one or more selected STP pairs. They were called "network control points (NCPs)".

Based upon the number dialing, switching offices on the CCIS network, known as "action control points (ACPs)" distinguish calls that need to be referred to NCP data bases before they are processed further. Initially these data bases were used for such things as providing regular call

terminations for reverse charge ("800" service) calls. The first data base service was offered in 1980.

By treating operator systems as ACPs, credit card numbers could be verified automatically prior to permitting the completion of these calls. Later, by adding criteria other than the called number, calls could be routed to different network terminations, taking into account such items as the calling number, the time and date, and/or the busy condition of the called line.

5.2. With the capability of referring calls to a central data base, a business company can have one unique telephone number throughout a country, a "National number". Then, calls to this national number may be directed to different locations depending upon the number (and therefore the location) of the calling line.

5.3. In the same manner, a number could be assigned to a person for use nationwide (maybe world-wide in the future?..). As the person moves around the country, the data base information for this "Personal number" could be changed accordingly.

5.4. To implement these features in the SPC network, new signaling messages known as "direct signaling" messages were added [12]. These messages carried information back and forth between the ACPs and the NCPs.

In their more developed state, the ACPs were programmed to request by voice announcement more digital information from the caller. For example, the data base could contain several different terminating numbers for a particular dialed number. These numbers might represent different departments of the same company or offer to answer the call in different languages. Thus, an announcement might request that, for the call to be answered in French, "please dial an additional 3."

5.5. A general name given to these features was "direct services dialing". This led to a further concept of using a NCP data base to define networks within networks. AT&T called it "Software Defined Networks (SDN)" [13]. These are "virtual private networks" using the facilities and switches of the public network.

Calls originated by subscribers to this service are routed via an ACP to a data base that contains public network addresses for numbers that are dialed over the private network. This means for example that a business with several locations may have a uniform and coordinated dialing plan for all locations within a city or country. Through service management computers the customer may change number assignments in the data base to meet his needs.

In the United States all of these service concepts were implemented and available to some degree prior to 1984. As CCS is introduced into other national networks these service concepts are expected to change in many respects the way telecommunication services in general appear to the user. *Telephone numbers will not longer be addresses but instructions to the switching systems.*

6. Local area signaling service (LASS) [14]

With the success of the SPC Network in the United States efforts were underway in the early 1980's to find and implement new uses, like Call Management Services, to promote CCIS between local offices. As mentioned earlier, the use of CCIS between local offices depended upon finding new revenues or advantages to the telephone administration to justify the added expense for this method of signaling. Therefore the key-word stress in the name LASS was for "services", new services. Later, the word "custom" was added ahead of LASS to give it a more commercial appellation, which became CLASS.

Unfortunately LASS or CLASS came at a time when AT&T agreed to divest its holdings in the local Bell operating companies (BOCs) and therefore could no longer control the introduction of these new services. Nevertheless trials of some of these services that had been planned proceeded in Harrisburg, PA and Ft Lauderdale, FL.

Many custom local signaling services were the realization of those proposed in the CMS studies (see section 3.3.3 above). The trials started in

May 1984 with general availability planned for 1986. The services were generally favorably received although there has been some repercussion from those who feel that the calling number display is an invasion of privacy [15].

As an indication of trends in the industry, with the BOCs purchasing switching systems from several different manufacturers, it was necessary for uniform operation to arrange for each manufacturer to include CLASS on their systems and, first, to define exactly for them the service descriptions and its specifications. Bell Communication Research (Bellcore) had to include them in the local switching system general requirements (LSSGR) that they issue and coordinate (see Chapter IX-3). This has delayed the general availability of this service. But there was more to introducing CCIS into the local areas of the United States.

7. Intelligent Networks [16] [3)]

Looking at signaling and SPC networks by Bellcore gave rise to a general reconsideration of the service and future switch needs and objectives of the BOCs. The divestiture required that the BOCs establish data bases similar to AT&Ts for line information, credit cards and 800 numbers, particularly for use in local areas.

The BOCs were becoming impatient with the long time required to process and coordinate the development of new services and features in the switching systems they were then purchasing from several manufacturers. As a result Bellcore took a new look at how to implement new services.

They started with the SPC data-based network services concept and extended it. First, they gave it a new name, viz. the "intelligent network (IN)." (No serious new development would be worth its salt if it did not have a distinctive name and acronym!..) They also gave new names for ACPs and NCPs, viz. Service Switching Points (SSPs) and Service Control Point (SCPs) respectively.

They visualized several steps in its development, the first – IN/1 – which is similar to what was the AT&T SPC network but, this time, using signaling system No. 7. By this time (1984) there were many long-distance networks in the United States competing with the AT&T one. Most of these new long-distance networks in the U.S. were planning to use signaling system No. 7. This was the principal reason Bellcore could not continue to follow the original AT&T lead. Later steps would be IN/1 + , IN/2, etc.. [4)]

8. The Move from CCIS to Common channel signaling No. 7

The AT&T network was based upon the use of signaling system No. 6 (see Chapter X-4). This was before the trend to digital networks gained momentum with the conversion of local offices to digital. One of the penalties of being first in any field of technology is that the technology will be rapidly obsolete.

But this, like Janus, is two headed: coming later into the SS No. 7 field, AT&T could develop a more advanced and higher capacity STP to serve its longer term future needs. AT&T made plans for converting its network to SS No. 7. This was more difficult than it seems obvious because the existing network and its services had to be kept operating, and expanding, while the conversion was made to the newer signaling system [17].

[3)] This book is intended to be a disclosure of the technical changes in the telephone industry. However, as we approach closer to currency it becomes more difficult to explain technology decisions and progress in the light of political, regulatory, and commercial considerations that only the passage of time will permit to see with greater perspective. Therefore full elaboration of the circumstances and conditions surrounding technical trends can not be fully explained here.

[4)] The Intelligent Network concept was championed by all switching equipment manufacturers, as a marketing ploy, if not by undertaking new system developments. Soon "intelligent" became the buzzword of the late 1980s.

9. Other Countries

This Chapter focuses on the United States because this was where the first extensive deployment of CCS took place. It was also the first place where advantage was taken of the new service opportunities afforded by CCS.

We have seen in Chapter X-4 that there was nearly no deployment of CCS based on System No. 6 in any other country than the United States. However, once the System No. 7 standards were agreed upon, planning and implementation proceeded in many countries, particularly in Belgium, Japan, and Sweden to extend considerably the usages of the new CCS signaling network, progress in deploying CCS No. 7 following the availability of SPC exchanges.

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CHAPTER X-7

TRADITIONAL SUBSCRIBER LINE SIGNALING, THE ALPHA OF ALL SIGNALING SYSTEMS

1. The ultimate basis on which all telephone operation rests is the subscriber line and the signaling over it

Subscriber line technology is a century old. Use of a two-wire pair for the subscriber line dates from 1883 (J.J. Carty) and common battery power supply to the station set from 1886 (Chichester Bell) or 1888 (Hammond V. Hayes) [1]. These practices have been and will remain the universal rule for many decades to come. Nearly 600 million twisted copper-wire pairs serve telephone subscribers throughout the world's local networks.

Rotary dials, introduced in 1896 in the United States at one of the first Strowger exchanges, are still used on a majority of these 600 million sets to provide automatic service. However the pushbutton keyset is progressively replacing the rotary dial and pushbutton sets are becoming a *de facto* quasi-standard for stations served from electronic exchanges.

2. The century-old traditional subscriber line signaling, so basic and universal until recently that it looked set to endure forever, justly deserves to be called the "*alpha*" of all signaling systems. It specially deserves this attribute by opposition to what is now the most modern and sophisticated of all these systems, i.e. the one for digital subscriber line to serve the customer's ISDN terminal and that we may call the "*omega*" of the signaling systems.

All types of telephone signaling, over junctions, trunks and long distance circuits, were initially based on the traditional subscriber signaling system. Its poverty-stricken language constituted both their basic feature and their smallest common denominator. Subscriber line signaling is breath-takingly simple and on it everything depended. It is so conventional and familiar that describing it in a history of signaling such as this may seem superfluous.

3. Yet setting down a precise but succinct description is by no means a simple exercise [1]. Such a description, abstracted from [2], is offered in Boxes A and B for the layperson because this book is, after all, somewhat in the nature of a reliquary. Any instructor required to inculcate the rudiments of telephony among young trainees

[1] Precisely describing the more usual and supposedly simplest mechanisms and how they operate would provide one of the best drafting exercises that could be set for aspiring engineers, e.g. "Describe in one or two pages one of the following subjects: subscriber line signaling, driving a car or riding a bicycle."

Early in the Second World War, the author (RJC) derived enormous pleasure from a handbook of instructions for bicycle-mounted light infantrymen, dated 1880, which had been exhumed from the archives for an army which, in the days of Vichy France, had no better means of transport. No less than 5–6 pages of detailed instructions were required for the infantrymen of 1880 to mount their machines, start pedalling and form orderly ranks in response to the successive words of command!

may find that text as a valuable reference.

4. The weaknesses of traditional line signaling [3]

The advantages of robustness and simplicity of the traditional subscriber line signaling system are to some extent offset by many drawbacks of which we shall simply mention the following:

i) the *vocabulary* of the signaling language used is extremely *poor*, consisting solely of the binary changeover sequences which are given by the "on" and "off" positions of the d.c. loop and, subsidiarily, of the action of the ringing a.c. signals and monitoring of the busy and ringing tones;

ii) *signaling* usually is possible *only during the call set-up* phase and cannot easily be achieved once the call has been set up;

iii) in the present era of electronics, the use of d.c. current loop interruptions as signals and of high-voltage a.c. ringing signals is not

Box A

Information transferred between suscriber station and exchange (according to the international terminology: ITU / CCITT terminology)

ELECTRICAL SIGNALS FROM CALLING STATION TO EXCHANGE

Seizure	– Handset "off-hook" (loop closed)
Clear forward	– Handset "on-hook" (loop open)
Numerical (or address) information	– By means of: * the dial (dial pulses/loop interruption) * the pushbuttons (multifrequency pulses)

ELECTRICAL SIGNALS FROM EXCHANGE TO CALLED STATION

Ringing current	– To actuate the bell (or tone-ringer) of the called station

ELECTRICAL SIGNALS FROM CALLED STATION TO EXCHANGE

Answer	– Handset "off-hook" (loop closed)
Clear back	– Handset "on-hook" (loop open)

AUDIBLE TONES FROM EXCHANGE TO STATION

Dial tone	– to indicate that the subscriber can proceed to dial, as the appropriate equipment is switched to the line
Ringing tone	– to indicate to the calling subscriber that the called party is being rung
Busy tone	– to indicate that the call attempt has to be repeated, because the called station is engaged or because congestion has occurred ("dial same number")
Special information (or number unobtainable) tone	– to indicate that the dialed number is incorrect, e.g. not in use ("dialing the same number is useless")

Box B

Traditional signaling between subscriber and exchange

To set up a connection to the desired party, a calling subscriber gives forward signals to the local exchange by means of the switch hook and the dial (or pushbuttons) of his telephone set. In the backward direction, the exchange indicates the progress of the call in the form of audible tones [2] and/or recorded annoucements.

To advise the called subscriber, a ringing current is sent by the called party's exchange; the called subscriber then rseponds by lifting his handset.

The connection will be completely released when both parties have replaced their handsets [3].

[2] In Recommendation Q.35 of its Volume VI.1, the CCITT reminds telecommunication entities of the advantages of using standard supervisory tones so that, in an international call, subscribers and operators can quickly recognize any tone transmitted, whatever its national origin.

Limits on tone cadences, frequencies and power levels are set out in the same Recommendation. Supplement No. 4 to CCITT Volume VI gives the particular values of tone cadences and frequencies in actual use in the different countries throughout the world.

[3] Forced release of the connection occurs automatically if one of the two parties forgets to replace his handset on the switch hook. In the switching equipment, a time-out device will trigger the release of the connection after a duration of between 1 and 2 minutes after the other party has replaced his handset on the hook. For a time-metered call, therefore, negligent calling subscribers are spared from having to pay too large an extra charge (only the duration of the time-out).

easily compatible with electronic components in the subscriber set and in the line circuit of the exchange;

iv) *signaling is* relatively *slow.*

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CHAPTER X-8

FROM THE 1960–1970s, SUBSCRIBER SIGNALING FROM A PUSH-BUTTON SET

1. Keyboards instead of dials

1.1. Our account of subscriber signaling systems would be incomplete without a mention of another important stage, namely signaling from push-button subscriber sets, a system which falls halfway between the oldest and simplest system and the latest system which will be used for digital terminals in the ISDN.

It is this stage, reached in the early 1960s, which to the subscriber constitutes the only tangible display of modernity in a telephone service because, being totally indifferent to whether exchanges operate in the electromechanical or the electronic mode, he naturally pays attention only to what he can actually see and handle.

The subscriber finds no difficulty in learning how to operate a push-button set and is appreciative of its faster dialing speed.

1.2. The superiority of push-buttons to rotary dials is and always has been fully obvious to telecommunication enterprises. Thus, the practice of fitting *push-buttons at operator positions*, both to simplify the job and to increase operation speed and operator output, was as old as the automatic service itself (see Fig. 1).

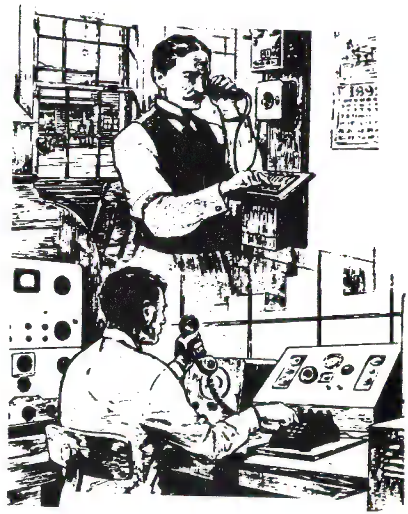

Fig. 1. Push-buttons were always the preferred method of placing calls automatically (from [1a])

1.3. Replacing rotary dials by push-buttons on a vast number of subscriber sets was, in both the nature and the magnitude of the task, quite another matter from fitting push-buttons at operator positions. The idea itself was brilliant and, for the engineer, an attractive one. For reasons of cost and difficulties imposed by technical constraints, however, for long, it seemed unworkable and somewhat utopian.

The advent of the transistor was to change all that.

2. Birth in the United States of push-button station signaling: the "Touch-Tone" and DTMF coding [1b]

2.1. At the end of the 1950s the invention of the transistor brought the cost of push-button signaling to a point where a push-button service could be offered at an attractive price. Much experimental work was carried out in the United States

at Bell Laboratories, including the study of different push-button arrangements.

2.2. A first attempt of customer push-button dialing was made as early as 1948 in the design of the initial No. 5 crossbar local exchange at MEDIA (Pennsylvania) [1c]. The signaling system used vibrating reeds with a code of 2-out-of-6 frequencies, similar to that used for circuit MFC signaling. Signal imitation by speech currents reaching the MFC receiver and detected as false digit signals led to this signaling system being regarded as non-operational.

2.3. An improvement in the coding of the digit signals was the arrangement now generically known as Dual Tone Multi-Frequency (DTMF) coding. In the DMTF code, a digit signal is composed of two frequencies emitted simultaneously when a button is pressed. The two frequencies composing each signal are taken from two mutually exclusive frequency groups of four frequencies each and the code is known as the "$2 \times 1/4$" code.

The low group frequencies of the $2 \times 1/4$ code of the Bell Laboratories were: 697, 770, 852 and 941 Hz. The high group frequencies were: 1209, 1336, 1477, and 1633 Hz.

These frequencies and their allocation to the various digits of the push-button keyset were later internationally standardized by the CCITT. Fig. 2 shows this allocation.

2.4. In the United States, AT&T, the originator of the DTMF code, has trade-marked the service using it as "Touch Tone", a trade mark that like, e.g., Kodak, is now frequently used as a generic term.

The DTMF push-button signaling system was developed by Bell Laboratories in the late 1950s. Technical trials were held in a step-by-step office at Hamden, Connecticut and in a No. 5 crossbar office at Elgin, Illinois, in 1959 [1d]. Fig. 3 shows the trial results comparing the dialing times with rotary dials and push-buttons as people learned to use the new "dials".

Further technical trials focusing on exchange equipment were held in 1960 in step-by-step and crossbar exchanges in Virginia and Maryland. In 1961 marketing trials took place in two cities in Ohio and in Pennsylvania. The economic provision of the Touch-Tone facilities at each type of local exchange/subscriber switching system was a development challenge for the Bell system (AT&T, Bell Laboratories and Western Electric), not unlike the challenge of providing direct-distance dialing (DDD) in long-distance switching.

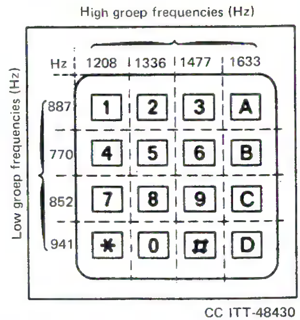

Fig. 2. Allocation of frequencies to the various digits and symbols of a push-button set (CCITT standard) (from [2])

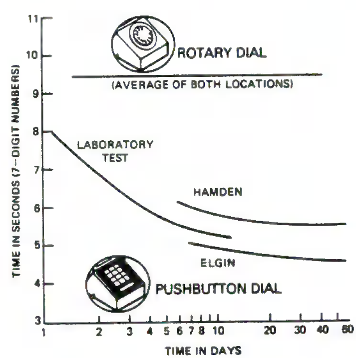

Fig. 3. Time to dial seven digits, comparing conventional rotary dialing with push-buttons (1959 technical trials at Hamden, Connecticut and Elgin, Illinois) (from [1d])

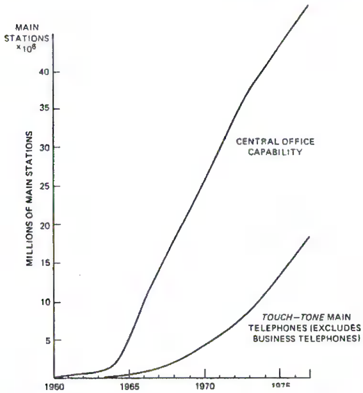

Fig. 4. Growth of central office Touch-Tone facility and main telephone Touch-Tone lines (from [1e])

2.5. The Bell System's first public offer of the Touch-Tone facility took place at the end of 1963. From the beginning of the 1970s, this new service facility proved a great success in the United States and expanded greatly (Fig. 4). By the end of 1976 about 70 per cent of Bell system lines could be provided with Touch-Tone services and more than 30 per cent of subscribers served by these lines were using the facility.

Touch-Tone calling was the first of the optional facilities introduced in the Bell System after World War II that required specific subscriber premises equipment and local exchange provisioning. This was especially the case for step-by-step exchanges. To adapt direct control exchanges of this type for Touch-Tone calling required the addition of a form of indirect control to register the Touch-Tone dialing digits and to out-pulse them, at a slower rate, as dial pulses. This amounts to a very simple form of register-sender without translation, code conversion, etc. Various types of Touch-Tone receivers for PBXs and local offices were designed by Bell Laboratories to cope with the diversity of loop and office situations.

3. Development of Push-button Signaling outside the United States. General Support For the DTMF System

3.1. Interest in push-button signaling was not confined to the Bell System and its Laboratories in the United States. By the late 1950s it was growing in Europe and, shortly afterwards, had started in Japan [3].

In point of fact, the European administrations showed scant interest, their sole concern being to meet the urgent clamour for new telephone connections. Then again, switching specialists like LM Ericsson, Siemens and Philips did not expect the administrations in their own respective countries to take the initiative and it was their own R & D departments which actually concentrated on push-button signaling. Their aim was not so much to fit push-buttons to ordinary subscriber sets as to fit them to the telephone stations served by PABX installations. In other words, different solutions to different problems, particularly through cheaper DC signaling using different resistors to obtain the push-button signals (see, e.g., [4,5]).

3.2. The success of the results obtained in the United States and widely disseminated in the Bell Laboratories publications (especially [6] and [7]) had the effect of broadening the field of study of push-button signaling and bringing the voice-frequency coding method to the forefront.

In Europe, incidentally, the early 1960s witnessed the first telephone applications of transistorized devices, coincidentally with the beginnings for MFC signaling.

3.3. In the development of push-button MFC signaling a number of basic principles was universally recognized at the outset:

i) frequencies should be chosen from outside the band used for tones and where the speech pattern was weaker;
ii) the signal code should be "self-verifiable" to preclude imitation by speech currents from the caller's microphone;
iii) unlike the American MFC system of signaling between exchanges, the digits could not

be preceded by a characteristic key signal (KP = "key pulsing" in the American MFC code). Nor could subscribers be asked to send an end-of-dialing key signal of the ST ("sending terminated") type, though this would have been highly practical in countries like the Federal Republic of Germany where subscriber numbers consisted of a variable number of digits.

3.4. All these principles had already been adopted for AT&T's Touch-Tone system.

For instance, AT&T's DTMF coding system was self-verifying: for a signal to be recognized as a dialing digit, two frequencies had to be present simultaneously, one belonging to the high frequency group and the other to the low frequency group. Each frequency moreover had to be precisely defined (± 1.5 Hz) and have a duration of more than 40 ms, and the level of each could not differ by more than 8 dB (the tolerances given are, if not international standard, at least the commonest). Failure to meet any of these conditions would invalidate a signal.

3.5. CCITT action was decisive for the world-wide standardization of DTMF coding and its associated frequencies. Once those manufacturers whose equipment used different frequencies but more or less the same values had agreed to bring their values into line with those intended for use everywhere, a general consensus was, after three years' of CCITT study, reached at the CCITT Plenary Assembly held at Mar del Plata (Argentina) in 1968. The DTMF signaling system subsequently became the subject of Recommendations Q.23 in Volume VI-1 of the CCITT Book [8].

3.6. For more than a decade the spread of push-button stations remained almost exclusively confined to the North American continent, although in Japan it occurred slightly faster than in Europe and, above all, on a much vaster scale [3]. From the late-1970s onwards, the use of push-buttons spread throughout the world [1] and, in particular, became an almost universal practice for serving subscribers connected to electronic exchanges.

4. CCITT action for the world-wide standardization of provisions relating to push-button subscriber stations – Configuration of the buttons

4.1. We noted in section 3.5 the role played by the CCITT during its 1965–1968 study period in defining standards for DTMF coding and its 2 x 4 frequencies.

4.2. However, the first thing the CCITT had to do was to find a push-button arrangement capable of universal acceptance. A standard configuration was intended to overcome the usual dilemma faced by any foreign traveller when confronted with a rotary dial on which the digits do not follow the same arrangement as at home [2].

4.3. Users see the arrangement of push-button digits as the simplest thing in the world. At most,

[1] To accommodate subscribers desiring push-buttons in offices not arranged to DTMF, integrated chips were available and widely used in telephone sets with push-buttons that sent out dial pulses in response to operating the buttons. Sets of this type are known as "decadic" dial sets and served a need for those desiring push-buttons without changes having to be made in central offices.

Another arrangement to implement push-button dialing in the same situation of a central office was, at a time, proposed by manufacturers outside of North America: for each depression of a button an interruption was created in the dc loop circuit. The purpose of this interruption was to give time for the central office to connect a receiver to the line so that this expensive equipment could be used more efficiently. This mechanical arrangement required fast connections to be made to a pool of receivers and did not prove to be reliable.

[2] This is particularly the case when the zero precedes the 1 instead of following the 9 in the usual way. Such specific national arrangements still persist as, when locally introduced in the early days of the automatic service before the CCITT (or, until 1965, its predecessor, the CCIF) existed, nobody regarded the automatic service as a matter of international interest.

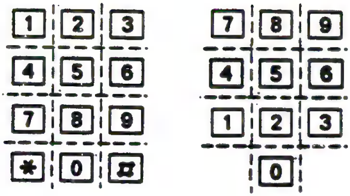

Fig. 5. Button configurations:
– on push-button telephone keysets (left side), and
– on commercial pocket calculators (right side)

a few who have to use pocket calculators fairly frequently may wonder why two different configurations of digits have been introduced for the two types of application (see Fig. 5). Would it not have been handier if one and the same configuration had been adopted?

It was not only such users who were intrigued by that question. When the CCITT approved Recommendation Q.23/E.161 entitled "Technical features of push-button telephone sets" at the 1968 Plenary Assembly [8], the differing arrangements led the technical press to level some harsh criticism at both the CCITT and the merits of its Recommendation.

4.4. Yet the CCITT arrangement was not defined without due consideration. Far from it! ... Indeed, it was preceded by a whole series of studies relating to human factors, first when the Touch-Tone was defined in the United States and subsequently in many other countries at the instigation of the CCITT itself. It was these studies which monopolized attention at the "Human Factors in Telephony" Symposia held at Copenhagen in 1963 [9] and at The Hague in 1966 [10].

Batteries of tests had been carried out on the behavior of subjects required to dial the long sequences of digits used in the local, long-distance and international services. Comparative tests of the two rival arrangements pointed to the conclusion that the CCITT push-button configuration was for human factors superior to that used on calculators.

4.5. Incidentally, questions were raised as to the logic behind the design of the calculator arrangement. The answer, little known and far less made public, is given strictly for the record: the calculator push-button arrangement, a matter within the competence of the International Standardization Organization (ISO), had been defined many years earlier, at a time long before the electronic age, when the only calculators were mechanically operated by means of arms and rods. It was adopted for the sake of making infinitesimal savings on the metal used in those parts and had since remained as immutable as driving on the left in the United Kingdom (or, for that matter, on the right in so many other countries). The decision dates from an age when the number of mechanical calculators throughout the world must have amounted to a few thousand as opposed to the hundreds of millions of pocket calculators that exist nowadays.

Again, for the record, it has to be noted that the telephone push-button arrangement was developed in the first half of the 1960s, i.e. before the pocket calculator had made its debut, so the reflexes of the subjects used in the comparative experiments on the two types of configuration were completely spontaneous and in no way conditioned by practice on that little marvel of human ingenuity.

5. Buttons 11 and 12 and the problem of finding names for them

5.1. The telephone push-button arrangement standardized by the CCITT covered the configuration not only of the 10 digits in our decimal system but also of the buttons which correspond to signals 11 and 12 (or 11 to 16) in the DTMF code.

Using four frequencies in each of the low and high groups, the DTMF code offers 16 combinations or signals. In point of fact the coding used is usually truncated and uses not 4 but only 3 of the frequencies in the high group, thus affording 12 signals. The two code signals 11 and 12 are allocated to the push-buttons which lie to the left and right of the zero, respectively, on the bottom

line. (By far the majority of push-button sets have only 12 buttons and the CCITT 16-button arrangement has in the present state of the art remained more theoretical than practical in its application.)

5.2. Code signals 11 and 12 are "function signals" for enabling subscribers to call up (or control) the various facilities [3] offered by SPC exchanges. It will be recalled that research into such facilities had provided the chief motivation of the decision-makers who took on the study of an SPC system, namely to offer the subscriber a wide range of tailor-made services designed to provide all the satisfaction of an intelligent yet completely automatic service.

Buttons 11 and 12 are therefore gateways to all that an SPC system has to offer. An engineer travelling abroad has only to glance at the telephone dial and note whether or not it includes these two buttons to form an idea as to what sort of central office serves the set and, by extrapolation, how modern the country's network is (provided, of course, that the controls are not simply for giving access to the PBX services at the hotel in which he happens to be staying).

5.3. The names to be given to buttons 11 and 12 were the subject of lengthy semantic discussions within the CCITT. We shall refer to them here simply on account of their anecdotal value.

AT&T and its Bell Laboratories had chosen the star symbol (*) for button 11 and the "number" symbol (#) for button 12.

There was no difficulty as regards generalizing the star symbol and its name on a world-wide basis because, thank God, everyone knows what a star looks like! However, that was by no means the case with code symbol 12: the CCITT found that the symbol #, so widespread in the United States, was unknown elsewhere, even in the English-speaking countries in general and the United Kingdom in particular.

5.4. The CCITT studies included surveys in various countries among representative samples of the telephone subscriber population. Their purpose was to ascertain what the symbol # meant to the subscriber and what it should be called in the language of the country.

Reading the results of these surveys had a certain charm and it is a pity they have not been exploited in learned journals on comparative linguistics and semantics. Copy-hungry journalists, too, could have found in them material suitable for the pages of intellectual distraction which the large-circulation newspapers offer readers in their weekly supplements. The results are now lost or buried in someone's archives, but the following perfectly representative example is offered for what it is worth: in the United Kingdom, one of the favorite names for the symbol # was the perhaps bucolically inspired words "fence" or "faggot" – a far cry from the original meaning chosen for the push-button in the United States. [In the United States some said the "number sign" symbol was known as an "octothorpe" (an octopus?)].

5.5. Playing both on words and on the shape of the symbol # with a view to making it recognizable in some countries under the name "square", yet without deviating too far from its American design, the CCITT – after a certain amount of intellectual gymnastics – came up with the following definitions: for code 11, the symbol on the left-hand side of the zero "is to be known as the star as translated in the various languages"; for code 12, the symbol (right-hand side) "is to be known as the square or the most commonly used equivalent in other languages. (In some countries, an alternative term (e.g. number sign) may be necessary...". (section 3.2 of CCITT Recommendation E.161) [11]).

5.6. The use of a characteristic color to identify each button had been suggested by Japan, a country justly renowned for its expertise in repre-

[3] In the jargon of telephonists these services are known as "vertical services". These are "subscriber selected services" as compared with the "horizontal services", i.e. regular telephone services, that are offered to all subscribers of the central office.

senting ideograms and pictograms [4]. Instead of the star and the square, the Japanese initially used red for button 11 and blue for button 12. The issues of taste and color are too subjective to be discussed, however, and for international purposes the idea was dropped.

It must also be recognized that the standardization of the push-button arrangement was heavily influenced by the fact that the overwhelming majority of telephone sets in North America were already of the push-button type.

[4] A quiz. What is the difference between a symbol and a pictogram? The CCITT gives the following answer (Recommendation E.121, Volume II.2):

"A pictogram is a simplified pictorial representation. It is used to guide people and tell the person how to achieve a certain goal. It consists of more or less realistic elements. Pictograms should be self-explanatory.

A symbol is an abstract pictorial representation; it stands for something and tells a person what he is faced with. It is not necessarily realistic and often requires a learning process in order to be understood."

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CHAPTER X-9

SIGNALING OVER THE SUBSCRIBER LINE IN AN ISDN STRUCTURE

1. Preliminaries. A good question: what is ISDN?

1.1. This Part X on signaling would be incomplete without at least a brief description of the latest member of the signaling system family, i.e. signaling over the telephone subscriber line in an ISDN structure. This system is peculiar in having a dual property:

- it is by definition an international system: its specifications must be faithfully adhered to if there is to be universal ISDN connectivity between every country having its own ISDN network;
- it is by nature a system for specifically national use in that, basically, it is intended for application in local public telephone service networks.

1.2. Having mentioned this system without explaining elsewhere what we mean by the *ISDN* (or to give it its full name, the *"Integrated Services Digital Network"*), let us now briefly describe it. For it is not enough merely to stress that here we are dealing with what telecommunication operators and equipment manufacturers alike regard as "the mode and the affair" for the present and coming years, say from 1987 to the end of the 1990s.

Any attempt to:
- describe the ISDN concept in détail;
- explain the gradual emergence of the concept, born within CCITT as a result of international discussions stretching over the lengthy period from the early 1970s to the end of the 1980s to which this book takes us [1];
- and cover all the indecisiveness that occurred during the slow ripening of the concept, and all the obstacles that had to be overcome before a general consensus was reached as to its modalities,

would in itself fill a tome even weightier than this one.

There is a wealth of technical literature on the ISDN: first the CCITT Blue Book [1], then books such as [2–7], even telecommunications review devoted to ISDN, such as [8], and, finally, countless reports in technical journals. Writings abound and the telecommunication specialist seeking to condense so much information finds himself virtually overwhelmed by its sheer bulk. The trouble according to some is that the steady bombardment of articles is so intense that we may not be able to see the forest for the trees. For want of a general overview, one might lose sight of the reasons behind this or that component of ISDN architecture and protocols.

1.3. So, in this preliminary section and in the context of a technological history book, we must simply confine ourselves to *skimming the surface* of the ISDN from a *historical standpoint* and essentially with the *non-specialist* in mind. This will now be done in the following three boxes:

[1] Assuming that it survives, the CCITT will continue for many more years to discuss the ISDN, initially the "narrowband" ISDN and later the "broadband" ISDN.

- Box A: definition of the ISDN as given in detail by the CCITT and according to its "sacrosanct" texts,
- Box B: short chronological summary of CCITT studies towards ISDN,
- Box C: comments (for the layperson) on what a typical ISDN structure will be.

Box A

The CCITT definition of ISDN
(an extract from CCITT Recommendations [1])

1. "An ISDN is a network, in general evolving from a telephony Integrated Digital Network (IDN), that provides end-to-end digital connectivity to support a wide range of voice and non-voice services, to which users have access by a limited set of standard multi-purposes user-network interfaces". (*Recommendation I.110*)

...

" In order to standardize all necessary aspects of ISDN the CCITT has divided the subject matter into a number of distinct (but obviously related) areas. Five of these areas are the following:
- 1) Services (I.200 series of Recommendations),
- 2) Network aspects (I.300 series of Recommendations),
- 3) User-network access and interfaces (I.400 series of Recommendations)."
- 4) Internetwork interfaces and ISDN maintenance principles (I.500 series and I.600 series of Recommendations).

...

2. "An objective of ISDN is that a small set of compatible user-network interfaces can economically support a wide range of user applications, equipment and configurations. The number of different user-network interfaces * is optimized for user flexibility through terminal compatibility (from one application to another, one location to another, and one service to another) and to reduce costs through economies in production of equipment and operation of both ISDN and user equipment.... Another objective is to have the same interfaces used even though there are different configurations (e.g. single terminal versus multiple terminal connections) or different national regulations." (*Recommendation I.410*)

3. ISDN aspects are further supported by other CCITT Recommendations both inside and outside the I series (e.g. on digital switching, interworking between ISDN and other (data) networks, ISDN charging and, more specific to this chapter, "User-network signaling" dealt with in the Q.920-Q.940 series published in 1989 in Volumes VI-10 and VI-11 of the CCITT Blue Book).

* Note: Some CCITT definitions (*Recommendation I.112*):

– *User-network interface* = the interface between the terminal equipment and a network termination at which interface the access protocols apply,with:

– *Terminal Equipment* = equipment that provides the functions necessary for the operation of the access protocols by the user

– *Network Termination* = equipment that provides the functions necessry for the operation of the access protocols by the network. (The network termination provides essential functions for transmission purposes.)

– Access protocol = a defined set of procedures that is adopted at a specified reference point between a user and a network to enable the user to employ the services and/or facilities of that network.

Box B

Short chronological summary of CCITT studies in preparation for the ISDN ("From vision to reality" [5a])

1968 – "Special Study Group D" was entrusted with the study of questions related to PCM and the coordination of work going on in the other CCITT Study Groups in the digital field. The vision of ISDN emerged in 1972.

1972–1976: CCITT was active in the field of digital transmission. It was also the period during which digital switching was moving from the laboratories into operation in telephone networks.

1976–1980: Special Study Group D has become a regular CCITT Study Group (SG XVIII):
- Studies on customer access to the ISDN (the so-called"user/network" interfaces)
- Adoption of the principle that ISDN will evolve from the digital telephone network
- CCITT definition of the ISDN

1980 – First ISDN Recommendation from CCITT (Rec. G.705 of the VIth CCITT Plenary Assembly in Geneva).

For attaining agreement on ISDN recommendations, five Working Parties and an "Expert group on ISDN matters" were set up in SG XVIII during the 1980–1984 period, with the latter to hold four annual meetings:
- January 1981, Innis Brook (USA)
- February 1982, Munich (FRG)
- February 1983, Kyoto (Japan)
- February 1984, Brasilia (Brazil)

SG XVIII met in June every year and, in June 1984, succeeded in drafting the first set of ISDN Recommendations which were approved by the VIIIth CCITT Plenary Assembly at Torremolinos (Spain) in October 1984.

Box C

For the layperson, some comments on what is a typical ISDN structure

Three preliminary comments deserve to be highlighted for the layperson. (To anybody actually involved with the ISDN, these comments may seem somewhat naive!)

First comment: Access to the ISDN via a digital telephone exchange

In a national network, an ISDN customer normally accesses the same digital local exchange as a subscriber to the normal telephone service. In the subscriber line interface stage of the equipment of this digital telephone exchange, "ISDN line" modules coexist with "analog telephone line" modules. Specific ISDN modules (hardware and software) exist or are retrofitted in the modular architecture of the exchange to provide it with the ISDN capability. These include modules for the CCITT No. 7 common channel signaling system to permit the transfer of the ISDN signaling information beyond the exchange and provide its interexchange signaling in the public telephone network (see section 6.3 hereafter)

For the existing non-telephone services that an ISDN network has to offer to its customers, interworking must take place between:
- the ISDN access via the telephone network;
- public data networks (circuit-switched mode orpacket data mode).

Box C (continued)

This interworking process takes place:
- either in the local ISDN-enhanced telephone exchange,
- or, (more generally and especially in the first phase of a national ISDN implementation), in another exchange higher up in the hierarchy of the telephone exchange network. An exchange with these functions of interworking with public data network(s) is usually called a gateway.

Second comment: Complexity of the equipment at the ISDN customer premises

For a non-expert in ISDN subtleties, it is often a surprise to learn that one essential component of ISDN architecture is the equipment to be installed at the customer premises (and owned by him), and further that this equipment is far from being a simple, easily identifiable unit, as for example a telephone set or teleprinter. Even in its simplest form, corresponding to the connection of the customer to its exchange by an ordinary telephone subscriber loop, the ISDN equipment at customer premises will often be a relatively complex installation serving different terminal units, with each or some of them corresponding to a specific service. Some have even compared the customer's installation to a miniature LAN (Local Area Network). One of the standard types of customer equipment installations is described and recommended by the CCITT: in it, two passive buses can serve up to eight terminal units in a point-to-multipoint mode of ISDN operation.

Customer-owned equipment functions internally in *a four-wire mode* of transmission, with separation of the two directions of transmission and reception. When the provision of the ISDN "Basic access" was being studied by the CCITT, one of the most difficult problems to solve was the provision of duplex transmission, via an existing 2-wire telephone loop, between the two sets of "4-wire equipment" at:
- the customer-owned plant, and
- the digital exchange.

Third comment: Wide diversity (of both type and configuration) of terminal equipment to be served by one ISDN access point at the ISDN customer's premises

A fundamental requirement of the ISDN is that it should supply the customer with *a single access point* to provide him with the broad range of services offered by the ISDN. The multiplicity of these services is matched by an even greater diversity in the ISDN *terminal equipment* at the ISDN customer's premises. Such equipment may itself consist of a set of differing *terminal units*. There is thus a triple diversity reflecting three distinct but compounded issues:

– first, the diversity inherent in the nature of the specific *service* to be obtained from a terminal unit;

– second, the diversity of *configurations* of the various units which may be used in the terminal equipment of an ISDN customer;

– third, and even more critical than the two just mentioned, a diversity due to the terminal equipment – and the terminal units in it – being owned not by the telecommunication agency but by the ISDN customer, which means that they are obtained on a free open market and made by innumerable *suppliers*.

A prerequisite for the development of a consistent ISDN structure was therefore a strict specification to standardize the characteristics of the interface at the ISDN access point. The standardization requirements would be obligatory not only for the telecommunication agencies, i.e. the network providers, but also for the manufacturers supplying office automation equipment.

2. "Digital subscriber signaling" (DSS), a most sophisticated system

2.1. With ISDN and its need for the transmission of digital information over existing 2-wire subscriber telephone loops, subscriber line signaling for ISDN customers, or "digital subscriber signaling" (DSS), has now appeared. It is an extraordinarily complicated and sophisticated system: intended for application to every telecommunication service whether for transmitting voice, data or images, it marks the ultimate refinement in signaling.

In section 2 of Chapter X-7, we described the century-old traditional subscriber line signaling as the *Alpha* of all signaling systems because of its simplicity and universal use. It has to be considered as the ancestor which all subsequent systems have had, if not to model themselves on, at least to take into account if only for its rudimentary set of signals.

In the now long line of signaling systems, we would be equally justified in reserving the *Omega* for the system to which this chapter is devoted. The latest in its line, it is an exemplary culmination of the technology of our time owing to its use for all services, its complexity and sophistication, the numerous design obstacles that have had to be overcome and, lastly, the way in which it was developed within the tight economic constraints imposed by the need to manufacture for implementation on a vast scale.

2.3. ISDN line signaling takes its place in the great technological revolution of our times, namely network digitization, which in the coming decades will steadily transform the Plain Old Telephone System into the ISDN multi-service network. Transmission of digital information over the subscriber telephone loop to serve multi-service ISDN terminals, with its signaling over this telephone loop, represents the last chapter of the end-to-end digitization of networks.

2.4. At the time of writing (1988), transmission of digital information over the subscriber telephone loop and its signaling are only beginning to be implemented. The essential point is, however, that unanimous agreement has been reached on the subject at world level. At its VIIIth Plenary Assembly held in Torremolinos (Spain) in 1984, the CCITT defined (I-series Recommendations) what will be the standard structure of the ISDN network. This definition marked the end of studies conducted over more than eight years (see Box A). Those studies took into account the results of far-reaching research in different countries concerning the maximum bit rate admissible over metallic pairs serving subscriber stations in the local distribution plant of a telephone network.

The I-series Recommendations approved in Torremolinos were contained in Volume III-5 (450 pages) of the CCITT Red Book (Geneva,1985). They defined not only the signaling processes and protocols for ISDN connections but also the ISDN concepts, the ISDN channels, etc. They described many ISDN models, e.g. the configurations of the customer terminal equipment. A profusion of type-models, tables, figures and flow charts inserted in these Recommendations was intended to assist the reader to develop an insight into the substance of the CCITT texts [2].

In 1988, after another active study period, the 1984 CCITT Recommendations on ISDN have been largely developed and enhanced by the IXth CCITT Plenary Assembly (Geneva). The largely expanded set of these Recommendations covers no less than five Volumes (Volumes III.7, III.8, III.9, VI-10 and VI.11) of the 1989 CCITT Blue Book [1], i.e. more than 1300 pages!

[2] However, it may be difficult for the non-specialist to find his bearings in this maze of convoluted and entangled CCITT clauses. Fortunately – for the reader as well as for the author – only ISDN line signaling in the "Basic access" (i.e. the access by an ordinary telephone subscriber loop to the ISDN customer) is to be briefly covered in this chapter.

3. Two fundamental requirements for ISDN subscriber line signaling

The studies of the access of an ISDN customer to the ISDN network via a subscriber line of a local telephone network and of the ISDN signaling over this line were determined by two fundamental considerations:

(i) – *for economic reasons*, and due to the very high capital invested in the local plant of telephone networks [3], the use of the existing pairs of the metallic telephone subscriber loops of a local telephone network was considered in the early-1980 CCITT studies on ISDN as an absolute requirement for an initial and general implementation of ISDN customer connection to digital exchanges.

(ii) – the signaling system had to be *common*:

• to *a set of services* (voice, data, fac-simile, etc.) and of modes (circuit-switching mode, packet switching mode),

• to *a set of two channels* ("B" channels) to be utilized indiscriminately/concurrently for the purpose of conveying information related to various services.

4. The ISDN "B" and "D" channels. The "Basic" access and the "Primary Rate Access"

4.1 The ISDN "B" and "D" channels

Two basic types [4] of "ISDN channels" [5] are specified and defined (section 2 of CCITT Recommendation I.412 on ISDN user-network interfaces):

– the B-channel, a 64 kbit/s (two-way) channel (with a bit rate value corresponding to that of voice coded in PCM), intended to carry a wide variety of user information streams and particularly voice encoded at 64 kbit/s; a distinguishing characteristic of a B-channel is that it does not carry signaling information for circuit switching by the ISDN;

– the D-channel, a two-way channel primarily intended to carry the ISDN signaling information for circuit switching by the ISDN and subsidiarily for packet-data transmission.

4.2. Utilization of the D channel

In an overall ISDN connection between calling and called party, the D-channel is only in use [6]:

– on the subscriber loop interconnecting the local ISDN exchange and the equipment at the customer premises, and

– internally within the equipment at the customer premises, between each terminal unit and the Network Termination ("NT") device which provides access to the subscriber loop.

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[3] See Habara and Aratani in [9]: "(For a telecommunication agency), capital investments in the local telephone network occupy a large part of total network investment. For example, the investment in the local exchange plant (mainly the subscriber loops and local switches) of the existing Japanese telephone network accounts for 60 per cent of the investment in all networks."

[4] Two other types of ISDN channels were also defined by the CCITT in 1984. Far less important than the "B" and "D" types and not so much used at present, a mention of them here is justified solely by a desire to give a faithful reflection of the CCITT texts. We refer to:

– the "H-channel" for various dedicated user information streams of larger bit rates than a B channel;

– the "E-channel" which may be used as a subsidiary channel to carry signaling information for circuit switching by the ISDN.

[5] An "*ISDN channel*" represents "*a specified portion of the information-carrying capacity of an ISDN interface*" (CCITT Recommendation I.412).

[6] Strictly speaking and to conform to the official terminology, the name "B-channel" is to be used only in the two restricted domains mentioned. However, on routes of the telephone network between ISDN exchanges, B-channel information is directly transmitted over "64 kbit/s channels" of PCM primary or higher order multiplexes connecting these exchanges. Under its official name of B-channel applying to the two restricted domains as mentioned and, between exchanges, under simply the name of 64 kbit/s channel, the user information of a B-channel is thus transmitted in an ISDN connection without alteration throughout the whole digital telephone network.

4.3. The "Basic Access" and the "Primary Rate Access"

4.3.1. The access from a digital exchange to an ISDN customer's equipment (or vice-versa) corresponding to the use of a metallic subscriber loop of the local telephone network is called the "*Basic Access*" (Recommendation I.430). Its interface structure is composed of *only*:

– two B-channels (64 kbit/s), and

– one D-channel (16 kbit/s).

With Basic Access, the customer terminal equipment with its "Network Termination" device is able to serve up to eight terminal units. These units may be of different types according to the nature of the specific service to be obtained by one or another of them. A detailed description of the various interfaces within an ISDN customer installation and of typical terminal unit configurations [7] in Basic Access is given in CCITT Recommendations I.411 and I.412.

4.3.2. Besides the "Basic Access" there is another type of access to an ISDN customer terminal equipment: the "*Primary Rate Access*". It corresponds to the case of an ISDN customer having a sizeable plant: this equipment is not then connected to the exchange simply by an ordinary subscriber line of the local telephone network, but by a primary-multiplex PCM link. Depending on the standards in force in his country, this link provides the ISDN customer with (up to) either 23 or 30 B channels [8].

5. Digitization of the subscriber loop. 1978–1983 studies. The various solutions. The post-1985 choices

5.1. In the late 1970s many studies on the behaviour of telephone subscriber loops for transmission of data at high bit rates were carried out in most of the developed countries, in extensive and detailed surveys of their various and very different local networks (see, e.g., [10–14]). The surveys had to take into account the wide diversity existing in loop lengths and conductor gauges, etc., and also the various types of distribution networks existing within a country [9]. The object of the surveys was to obtain representative models of the distribution of loop characteristics at frequencies up to 100 or 150 kHz.

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[7] Of the various configurations, the one expected to be dominant is the "point-to-multipoint passive bus configuration", serving several "terminal units" ("TEs" in the list of CCITT acronyms). The terminal unit connection is made via twisted pair wiring which provides a 4-wire mode, with two pairs, each corresponding to one direction of transmission, in what is called a "bus"). The buses can support ISDN sockets for up to 8 terminal units. (Annex A to Recommendation I.430).

Terminal units may be connected at random points along the full length of the twisted pair cable. This means that the Network Termination ("NT" in the list of CCITT acronyms) receiver must cater for pulses arriving with different delays from various terminal units. For this reason, the length limit of the buses for the point-to-multipoint configuration is a function of the maximum round-trip delay in the ISDN customer's installation.

[8] In the Primary Rate Access, the "user-network" interface structures correspond to the primary rates of 1544 kbit/s or 2048 kbit/s, according to the national use of one or the other of the two CCITT multiplex standards for PCM transmission.

The *primary rate* interface structures are composed of B-channels and one D-channel. The bit rate of this D-channel is 64 kbit/s and:

– at the 1544 kbit/s primary rate, the interface structureis *23 B + D*.

– at the 2048 kbit/s primary rate the interface structureis *30 B + D*.

[9] In fact, the pre-1982 loop surveys were based on a first approach of the ISDN channel structure which comprised only one B channel and a D channel of only 8 kbit/s. It was due to the results of these surveys that the CCITT expanded this structure and upgraded it to the now standard 2B + D structure for the Basic access, with a D channel of 16 kbit/s. The popular catchphrase during discussions within the CCITT at this time was the famous Shakespearian-style quotation: "Two B or not two B ?".

On the basis of these surveys, telecommunication agencies had in the early 1980s to determine what would be the more appropriate method for using *2-wire* subscriber loops for independent digital transmission in both directions, from the user to the exchange and vice-versa, i. e. in *a 4-wire mode*.

A representative chronology of these studies may be found in an extract of a report (see Box D) on the successive "International Symposia on Subscriber Loops and Services, or, shortly, ISSLS" (the "ISSLS" is a group of experts in the field that meets every other year since 1974). (As a matter of fact, the papers presented at the ISSLSs were only samples of many more studies, most of them reported in articles of well-known technical journals, e.g. [15–19].)

Box D

A summary of studies on transmission of data provided out-of-band over working telephone subscriber lines, reflecting the successive meetings (1974–1986) of the ISSLS

(from R.E. Mosher [25])

1st ISSLS, 1974, Ottawa (Canada): only a paper reporting "that cross-talk would not be a serious constraint in the deployment of analog multichannel carrier systems operating below 150 kHz on a telephone subscriber loop".
2nd ISSLS, 1976, London (U.K.): "Out-of-band signaling again appeared in the form of an equivalent 2-wire carrier system above the voice spectrum, for signaling and data (low speed?) transmission. It was observed that with this system the existing telephone plant could carry all foreseeable services except those involving moving pictures. (A prefiguration of the ISDN concept?)"
3rd ISSLS, 1978, Atlanta, Georgia (USA): "papers describing alternatives to bring digital signals directly to the telephone subscriber for both voice and data: one technique is proposed, later to be known as the ping-pong method. Several papers addressed common channel signaling on the subscriber line."
4th ISSLS, 1980, Munich (Germany): "Digital technology was by then well accepted in the local network and the ISDN was moving towards realization. Although new services were not well defined or quantified, it was understood that the network must and would evolve to flexibly serve them."

"The battle of ping-pong (or burst) mode versus echo cancellation continued, with papers advocating each as the preferred method of achieving bidirectional digital transmission on a two-wire subscriber line. No clear winner."
5th ISSLS, 1982, Toronto (Canada): "Eight papers were devoted to network evolution, or more specifically to ISDN. Three papers addressed network terminating equipment for ISDN. The battle between advocates of ping-pong and echo cancellation for bidirectional two-wire digital lines continued with six papers devoted to the subject. One paper described the implementation of an echo-canceller on a single NMOS VLSI chip. Many thought that this would settle the argument in favor of this more complex but more effective approach."
6th ISSLS, 1984, Nice (France): "ISSLS '84 continued the major themes of the previous symposia, but with frequent references to the changing legal and regulatory climate around the world.

The driving forces of subscriber network evolution were identified as rapid technological advances and the sharpening of customer demand. One advance was the merging of switching and transmission technologies and its implications for a changing topology that would bring network intelligence much closer to the customer."
7th ISSLS, 1986, Tokyo (Japan): " In Munich (1980), ISDN surfaced as an exciting concept. In Toronto (1982) and Nice (1984), ISDN also captured the delegates' imagination. In Tokyo, no one could escape the broadband services theme, and narrow-band ISDN was almost taken as an accomplished fact!" [26].

5.2. We shall not consider here the use of two pairs of a local cable to provide a true 4-wire access to the ISDN user.

At a time during the initial period of ISDN studies, this method had been proposed as a solution. Economic reasons and especially the existing local network situations in which most of the cable pairs are already assigned to subscribers prevent general use of this method. A true 4-wire solution may however be considered again in the future when the ISDN evolves into a universal broadband network. Bit rates up to 140 Mbit/s required in the broadband ISDN will need optical fibres to allow access to users. Completely new local networks of this type will have to be established [10] before there can be any new freedom to revert to the use of genuine 4-wire transmission.

5.3. For digital 4-wire transmission over a telephone loop, three solutions were in competition in the 1978–1983 period:

1) the frequency separation technique;

2) the time separation technique (burst or "ping-pong" method);

3) use of hybrid devices with "adaptative echo cancellation".

5.4. In solution 1), the data sent from both ends are separated by using transmission in two separate and non-overlapping frequency bands.

In solution 2), the digital stream is compressed into bursts transmitted at a high bit rate. The bursts are sent at alternate times for each of the transmission directions. After the time of transmission onto the line of a burst, a silent pause ("guard time") has to be inserted to allow transmission to be effective at the opposite end and to allow all transient and echo paths to dissipate. Only at that time can the opposite end be permitted to begin transmission of its burst of data.

Frequency-division in solution 1) and time-division in solution 2) offer a clear-cut separation between the two transmission directions. As such they could be qualified as "pseudo 4-wire" solutions. Both the methods 1) and 2) have the disadvantage of requiring a larger frequency band – more than double – than the one necessary for solution 3). At upper frequencies, attenuation of the line increases and therefore the maximum transmission distance in using solutions 1) and 2) is more restricted than with solution 3).

5.5. In solution 3), already proposed in 1976 [20], a hybrid at each end of the loop provides the 4-wire/2-wire conversion. This is the classical method in telephony, which had been known for over a century. Bits are transmitted and received simultaneously. However, when hybrids are used for data transmission at high bit rates, serious difficulties arise, especially those due to echoes resulting from the mismatch existing between the impedances of the loop and of the hybrid balancing network. The components of this balancing network can only provide a trade-off approximating more or less adequately the characteristics of loops of different lengths and gauges. Echo cancellers have therefore to be introduced [21–22]. These devices, to be installed at each end of the loop, need to be of a uniform type regardless of the nature/length of the loop if their cost is to be kept very low in a mass-production process, and should therefore be preferably of an adaptative nature. They will be provided in the form of a device with high-performance VLSI chip(s), to be mass-produced at a very cheap price per unit.

5.6. In most countries, the conclusions ot these early and mid-1980s studies were that the "adaptative echo cancellation" method was the preferred solution. However, in Japan, where the local networks are modern and serve a highly concentrated population of subscribers over rather short loops, the "burst mode" method was preferred.

[10] This has been the case in some field trial experiments of the mid-1980s, e. g. in France's Biarritz network, and in Germany (FRG) with the BIGFON project network (BIGFON = Broadband Integrated Glass Fibre Network).

Whatever the choice, the constraints for the design of the terminating devices to be inserted at both ends of the subscriber loop were of the most exacting nature, the three most important being:

- complete adaptation of the transmission system to the existing characteristics of whichever loop is selected from the very large population of loops in existence in the various distribution networks of a country;
- very low Bit Error Rate: BER $\leq 10^{-7}$, in a data transmission carried out at a very high bit rate;
- very low cost for the device, to be obtained through mass-production of customized VLSI chips.

The design of these devices [11] and VLSI chips was the challenge of the late 1980s.

5.7. For a national or regional standardization of the ISDN transmission system over the telephone loop, the decision to opt for the choice of the adaptative echo-cancellation method was only a partial step: the problem of defining a "line code" for the data transmission still had to be solved.

For this data transmission on the subscriber loop, many line codes have been in competition, each with its specific advantages [23,24]. The most important of these advantages is to reduce the frequency band of the signal spectrum and then, at its upper limit, the loop attenuation, therefore allowing longer loops to be accepted for the Basic access. To this purpose, and according to a technique well-known by data transmitters for high bit rate modems [12], "n" consecutive bits are associated and converted in a number (smaller than "n") of ternary or quaternary values, reducing substantially the number of transitions on the line, i.e. the "Baud" rate of the transmission.

What was the best type of code to apply? Will the choice of this code be a international standard, or at least a continental standard? For the economics of mass-production of the customized VLSI chips needed at both ends of any ISDN digital loop, the matter was important.

In most countries of the world, since the two terminating devices situated at each end of the subscriber loop are twin identical brothers, both of them will be supplied by the telephone agency. This agency is therefore the ruler, deciding what should be the characteristics of this device and the line code to be used by it. Will the choice be entirely national or will it be the matter for an international agreement to be concluded between many countries of the same geographic area or continent? An open question, very much debated in Europe during the last years of the 1980s...

In the United States, national regulations (FCC rulings) initially forbade that any part of the line terminal at the customer's premises may belong to the telephone (telecommunication) agency. A national standard was therefore necessary. It was determined by a working group "T1" of the American National Standards Institute (ANSI). The choice of this group was for the so-called code "2B1Q" (2 binary, 1 quaternary) [13], i.e. a 4-level code: the bits are grouped in pairs, and each pair is converted to quaternary symbols ("quads").

The other line codings under competition or approved by national telephone agencies are those described in a series of Appendixes to a Recommendation G.961 of the CCITT 1989 Blue Book. In addition to the AMI (Alternate Mark Inversion), a pseudo-ternary code) [14], the codes in competition to be used in the echo-canceller solution are:

- the 4B/3T (also called MMS43 = Modified Monitoring State) code, mapping 4 bits into 3 ternary symbols with levels "+", "0" or "-" . The 4B/3T code, selected by the German DBP after extensive studies (the DIGON project) in the early 1980s [2], is often considered as the "German code";

[11] These devices are not without analogy with the ones qualified as modems. It is to be realized that the 2B+D digital bit stream is transmitted over the loop in an analog form, as is the case for any transmission between modems on circuits of the public telephone circuits.

[12] Such as, in modems CCITT V.29, use of dibits with n = 2 and, in modems CCITT V.37, use of "quadbits" with n = 4.

[13] The 2B1Q had been initially proposed and considered to be the line code in the United Kingdom.

[14] The AMI code is the one defined in CCITT I.430 for transmission of the 2B+D bit stream inside the terminal equipment at the customer's premises. It is also the code utilized in Japan for data transmission in the burst (ping-pong) solution.

– the binary bi-phase code (BBP), in which:
  * a binary ZERO is represented by a negative transition in the middle of the bit period,
  * a binary ONE is represented by a positive transition in the middle of the bit period,
  * transitions at the bit boundary occur if the successive binary data bits are identical.

– the Substitutional conditional block code (SU32), a high performance code. The binary data is encoded into a ternary form. Each binary triplet is converted into a ternary duplet and is transmitted unless it is identical to the previously transmitted duplet.

6. Signaling for the Basic Access

6.1. In this chapter we confirm our attention to signaling for the Basic Access [15], such as it was defined in 1984 by the CCITT in conclusion of extensive work in its 1980–1984 study period.

Signaling carried over the D-channel is needed for ISDN connection of one or/and the other of the two B-channels of the Basic Access. It is of a "message/packet-data" mode, similar to the one previously defined for CCITT Signaling system No. 7, and is performed in accordance with what is known as protocols (see Box E), protocols now defined in detail by the CCITT after long and prolonged deliberations.

[15] The protocols relating to signaling via the D-channel also apply to the case of a D-channel (no longer of 16 kbit/s, but of 64 kbit/s) of the Primary Rate Access.

Box E

The protocol concept

Protocols have become one of the foundations of modern signaling, as well as of data transmission and "telematics" (i.e. facsimile, teletext, videotex, etc..).

The term "protocol" has invaded signaling terminology. It enters it in the wake of the vocabulary used by the "data communicators" who had in turn drawn inspiration from the language and definitions forged by Technical Committee TC 97 of the International Organization for Standardization (ISO). That Committee had and still has the difficult task [16]) of reconciling the approaches of computer manufacturers, as well as telecommunication enterprises, for finding ways of enabling computers of widely different characteristics and brands to hold remote dialogs.

The language of signaling and data communication protocols was constructed from scratch, mainly inside CCITT meetings, during the 1970s. Most of the terms used for describing and using it were already fairly common in everyday technical language but had then been assigned a very precise meaning, fixed by strict definitions, and thus a specialized vocabulary was forged.

The protocols have a language with standard semantics of its own, as well as a specific syntax which determines how combinations of words/concepts in the vocabulary should be strung together and how some of them may control others. This complicated syntax is often defined in the form of tables and matrices (numerous examples in the CCITT Book, e.g. in the Volumes on ISDN). They are frequently simplified by authors of articles on ISDN with diagrams representing the layers of protocol implementation.

[16] a difficult task indeed: while the telecommunication enterprises presented a relatively united front thanks to the CCITT which amalgamated their opinions, the computer manufacturers adopted anything but convergent positions. Many of them had set themselves the priority of having the internal protocols of their own systems recognized as international standards.

The D-channel protocols concern not only signaling between the two participants at both ends of a telephone subscriber line, i.e. the ISDN customer and a digital exchange. They also had to control what amounts to a configuration of different terminal units at the ISDN customer's premises. Each of them may

– claim access to the ISDN,

– or be called by the ISDN in a specific manner depending on its type (telephone station, data terminal, facsimile terminal, etc.) and, where appropriate, on its internal number within the private plant.

Note. – The D-channel protocols have been specified by the CCITT in such a way that packetized data (noted "p") and telemetry (noted "t") could also be transmitted over the D-channel, if appropriate. Such subsidiary uses of the D-channel would be concurrent with its signaling use and without prejudice to it. In this chapter we shall confine ourselves solely to the use of the D-channel for ISDN signaling (a use denoted "s" in CCITT texts). (This limitation excluding the "p" and "t" uses of the D-channel corresponds to the present practice followed in most of the countries that are feeling their way towards the ISDN.)

6.2. An essential property of the D-channel signaling is its *out-of-band character* enabling full duplex message communication between the customer equipment and the exchange, also during the conversation phase of a call and without interruption of the communication B-channel. The resulting additional capabilities compared with the present telephone service are:

– call progress messages allowing basic and supplementary service initiation and guidance,

– user-to-user messages, e.g. allowing in-call modification,

– the use of alphanumeric displays providing e.g. calling number display and call charge information.

6.3. Signaling over the D-channel takes place only:

– within the terminal equipment installation,

– between the ISDN terminal equipment at the customer's premises and the digital exchange to which the customer is connected. It does not extend beyond that exchange.

At both ends of an ISDN connection, specialized modules ("Signaling modules") in the digital ISDN exchange equipment have to convert the D-channel signaling messages into messages of Signaling System No. 7 (or vice-versa) to provide the transfer of the signaling information related to a B channel on the circuits between exchanges of the telephone network [17)] used to provide circuit-switched ISDN services. On any routes between ISDN exchanges (junction routes between exchanges of a Multi-Exchange Area, trunk or international long-distance routes), the use of Signaling system No. 7 is therefore an absolute precondition for any national (or agency's) ISDN implementation.

D-channel Signaling was modelled on No. 7 Signaling system. The signaling conversion between them takes advantage of the "design commonality" existing in their message-mode definition, especially for definitions of their vocabulary (signal repertoire), syntax and message formatting. Therefore, absolutely no signaling information is lost in their interworking, – a situation quite different from that which occurs too often when signaling systems of different generations have to interwork – , and signaling connectivity is ensured from end to end, i.e. from ISDN customer to ISDN customer.

[17)] In the same manner, for data-packet services to be offered to ISDN customers and to be provided through B channels, an interworking unit will have to be provided in the digital exchange serving the D channel. (Some of the interworking functions required in this unit are identical to functions performed in a customer terminal equipment of the public packet-data service.)

6.4. The traffic load on a B channel corresponds to the various busy occupations of this channel, busy during all the time an ISDN customer is connected to his remote correspondent. On the contrary, the traffic of a D channel is of a bursty nature, with a somewhat light traffic load, allowing therefore a potential use of the D channel for packet-data transmission (but with a preset priority for signaling messages) and teleaction (see Note to section 6.1).

7. Partitioning the digital subscriber signaling system in three conceptual "layers" [1,2], [4] and [27]

The D-channel protocols are partitioned according to the Open System Interconnection (OSI) model (definition of the OSI model in Recommendation X.200, Volume VIII-4 of the CCITT Book). This model offers a structured approach to protocol specification based on a seven layer architecture (Figures 1 and 2)).

Only the three lower layers in the OSI model were considered for the basic definition of the digital subscriber signaling:

- layer 1 (the physical layer)
  (CCITT Rec. I.430 in Volume III-8) [1]
- layer 2 (the data link layer)
  (CCITT Rec. Q.920–921 in Volume VI-10)
- layer 3 (the network layer)
  (CCITT Rec. Q.930–940 in Volume VI-11)

7.1. The *layer 1 (the physical layer)* provides the means to transmit bits of data across a continuous communication path which is common to both B and D channels. It is essentially the specification of a Time-Division-Multiplex (TDM) transmission system. It defines the TDM frame format to assemble these three channels (the 2 B + one D), together with the necessary activation/desactivation procedures of the physical connection at user-network interfaces.

In its Recommendation I.430, CCITT defines only the characteristics of this TDM system to be applied at the S or T reference points for the Basic access (i. e. for the main part of the ISDN customer's equipment, and for transmission on the two "buses" which may exist in such a plant). The 2B + D stream is transmitted in the form of frames of 48 bits each, each frame having a duration of 250 microseconds. The transmitted bit rate is therefore *192 kbit/s*. In the 48 bit frame, 32 bits are for the 2B + D channels and 16 bits are for specific functions: housekeeping, power activation and contention-resolution (when two terminal units TEs wish to send signals at the same time). These considerations apply to both directions of transmission.

Between the Network Termination of the ISDN customer equipment and the local exchange (what was called at one time the " U" reference point), the TDM system to be used to transmit the 2B + D bit stream on the 2-wire subscriber loop has not been defined by the CCITT. It is considered as a national matter since it depends very much on the structures of local networks, – which are very specific to each country – , and correlatively on the country's (or agency's) choice of using either the "adaptative echo cancellation method" or the "ping-pong" method.

Note: The expresion "2B + D bit stream" for transmission on the subscriber loop could be inferred to consist of $2 \times 64 + 16 = 144$ kbit/s, which would be misleading. In fact, the transmission requirements of the digital multiplex require the presence of additional bits to provide timing, synchronization and framing of the digital multiplex. It can be said that an unwritten quasi-agreement exists regarding the need to introduce an additional 16 kbit/s for such timing, etc., thus increasing the bit rate over the 2-wire loop to 160 (= 144 + 16) kbit/s.

7.2. The *layer 2 (the data link layer)* mainly serves the transport of the signaling information. It provides the means for delimiting the data transfer across the physical transmission. It also detects errors and, where possible, provides error correction.

Since, in many cases, especially with the "passive bus" configuration, there will be a small cluster of terminal units (a number n < or = 8) at

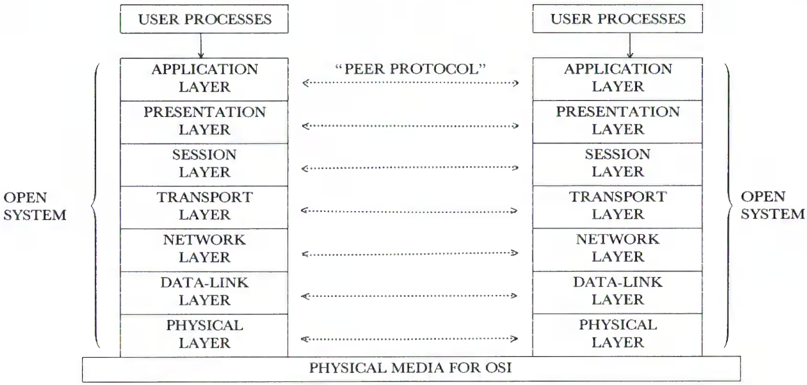

Fig. 1. – The OSI model. In this model, action of layers is sequential: an information element of layer "n" must pass through all the lower layers before it is transmitted, at the opposite end of the connection, to a "peer" layer of destination, i.e. to a layer of the same "n" order number. Within each layer the information to be transferred is *encapsulated* within extra-information added by the layer it is being passed through. Within each layer, protocols (the "peer" protocols) are contained to decide what form the extra-information must take. See Figure 2 in which this extra-information is called Protocol Control Information (PCI).

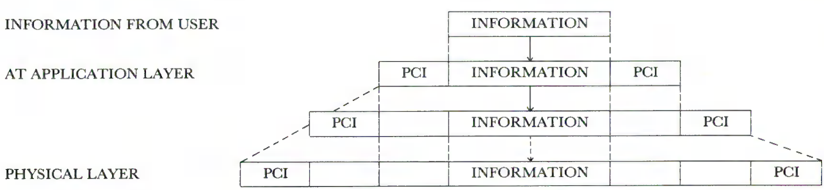

Fig. 2. At each layer "n", an encapsulation of the information coming from layer "$n + 1$" takes place with the addition of a "Protocol Control Information" (noted PCI in the figure).

the ISDN customer's premises in the Basic access, the D-channel signaling has to be able to establish a *point-to-multipoint* connection (multipoint within the ISDN customer's plant).

The D-channel *access protocols / procedures* that the CCITT defined were a direct transposition of those already defined by the CCITT for packet-data service according to the CCITT X.25 standards [18]. This greatly simplified the task of the designers of the ISDN subscriber line signaling system and offers an important economic advantage to manufacturers since it enables them to use identical VLSI components in producing equipment for both ISDN customer lines and packet-data circuits.

The "Link Access Procedures (LAP)" for X.25 terminals were, however, only for point-to-point connection and they had to be adjusted to provide the point-to-multipoint capability. This difference is reflected in two different CCITT acronyms, differentiated solely by their last letter:

- LAPB (B for "Balanced") for the packet-data dedicated circuits (point-to-point type),
- *LAPD* for the D-channels (point-to-multipoint type).

As for the LAPB, the LAPD applies the HDLC procedure (HDLC = High Data Link Control), a procedure well-known by data transmitters and representing a division into frames of the data stream, with information elements for the control and error protection of the transmission of data.

The main functions performed by the LAPD are:

- the demarcation of frames by means of flags, the alignment and the transparency of the transmitted frames (functions provided by the HDLC structure);
- the maintenance of frames in sequences when they are numbered;
- the detection and correction of errors with repetition of faulty frames)
- flow control.

[18] Recommendation X.25, in Volume VIII-2 of the 1989 CCITT Blue Book, defining "interface for terminals operating in packet mode and connected to public data networks by dedicated circuits".

The general structure of a LAPD frame consists of six following fields (each field consisting of one or several *octets*, i.e. 8 bits) transmitted in this order:

Opening Flag //
(1 octet)
// **Address** // **Control** // **Information** //
/ (2 octets) */ (1 or 2 octets) / (n octets)
(when present)
// **Frame check sequence** //
/ (2 octets) /
Closing Flag /
(1 octet)

* The second octet of the address field contains the identification of the terminal unit in an addressed terminating point.

7.3. The *layer 3 (the network layer)*, i.e. the "call control protocol", sometimes called "Protocol D", provides the means to establish, maintain and terminate network connections.

Its versatility and adaptability allow it to handle a large number of services and service facilities. It is also a universal protocol enabling ISDN customers to access public and private networks or to be used between private installations [4].

For circuit-switched call control the dialog between the user equipment and the network is carried out by messages of variable lengths. No less than 435 pages of Volume VI-8 of the CCITT Blue Book are necessary to list all the types of these messages, their content and the sequential order in which they are to be associated.

For the control of circuit-switched connections, 23 message types are stated, for respectively:

- call establishment (7 messages),
- call information phase (7 messages),
- call clearing (3 messages);
- miscellaneous (e.g. congestion control) (6 messages).

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Part XI

A geoeconomic overview of the environment for switching
A comparison between the 1960–1965 and 1985–1987 situations

INTRODUCTION TO PART XI

1. The purpose of Part XI is to show:

- the extraordinary growth of the telephone service over the past 25 years, and
- within that expansion, the major role played by switching activities.

Accordingly, the different Chapters that follow offer a *comparative analysis* of the situations prevailing in *1960–1965* and *1985–1987*, i.e. the two periods which correspond to the beginning and end of the time-span covered in switching by this book.

The *analysis* is of the *geoeconomic* nature, in other words both economic and on a world scale. It highlights the considerable impact of the profound changes that have occurred in the *organizational structures* governing:

- telephone service operating agencies, the ones known in the trade as "Operators" (but not to be confused with those seated at the switchboard!);
- switching equipment manufacturers.

2. Chapter XI-1 gives an account of the most concrete or rather the most easily discernible situation, namely that of telephone deployment between 1960 and 1985. Chapter XI-2 analyses demand in the 1960s and 1970s, while Chapter XI-3 outlines the characteristic features of "telephone operators" in 1960 and 1985.

Chapter XI-4 goes on to give a financial evaluation of world spending by "operators" on switching equipment and to describe the close ties that exist in relations between "operators" and suppliers.

Lastly, Chapter XI-5 offers a comparative analysis of the structures of switching equipment manufacturing companies in the period 1960–1965 and 1985–1987, ending with a description of the concentration that has taken place in the industry.

CHAPTER XI-1

A WORLDWIDE OVERVIEW OF TELEPHONE DEPLOYMENT BETWEEN 1960 AND 1985

1. Telephone statistics and their proper interpretation

1.1. Statistics offering a comprehensive picture of telephone development in the various countries of the world are the subject of numerous publications. They are widely used for comparative analyses of the telephone development in these countries [1).

To be used properly, these statistics – which give extraordinarily precise, if somewhat illusory, figures – must be interpreted with circumspection on account of the following main pitfalls, which should be avoided.

1.2. *First pitfall*: confusion between "subscriber lines" and "telephone sets of all kinds".

Nowadays, frequent reference is still made, both in statistics and even more in proud official statements, to the number of "telephones" in a country, (i.e. the number of "telephone sets of all kinds" [2)). This figure as opposed to the number of direct exchange lines (in short, "DELs"), also called in American terminology "main stations", does not indicate the degree of development of a telephone network. The DEL number does, since it indicates the amount of telephone exchange capacity in use.

The practice of quoting the number of telephone sets of all kinds in a country or area may present some interest from the sociological point of view [3). However, it should now only be regarded as a long-maintained hangover from the end of the last century when every telephone set was still covered by A.G. Bell's or T. Edison's patents and was carefully registered so that royalties could be collected. Obviously, this figure is irrelevant in our days if we note that in many of the countries with the most highly developed networks, anyone can buy a telephone set in a shop. The agency (Administration or private telephone operator) is no longer the sole supplier and therefore has no control over the number of such sets [4).

1.3. *Second pitfall*: confusion between the number of subscriber lines installed and the number of lines in service.

[1) The best known and widely used publications would include:
- "Yearbook of common carrier telecommunication statistics", published by the ITU since 1971;
- the famous "World Telephone Statistics" published by AT&T from time immemorial until 1984 when publication ceased, (resumed in 1988);
- "International Telephone Statistics" published by Siemens from 1966 onwards;
- Tables published annually in the "Electrical Communication" review of the ITT Group (generally in the first quaterly issue), until 1985 when publication ceased.

[2) which in the case of Switzerland, for example, includes the thousand sets at the ITU Headoffice although there are no more than 80 lines linking its PBX to the local exchange.

[3) with some (rather weak) correlation (a "R" ratio) between the number of such sets and the number of "direct exchange lines", within a particular country or metropolitan area. According to calculations made for 1982 by P. Luhan [1], the "R" ratio varied at this time from 1.90 in North America to 1.28 in Asia excluding Japan.

[4) Since the mid-1980s many of the most developed countries have stopped quoting the "number of the telephone sets existing in their country" in their yearly telecommunication statistics.

These two values generally differ by as much as 15–25% owing to the number of lines which must be held in reserve in order to ensure that connections which potential customers are bound to request in the coming years can be made available without excessive delay [5].

1.4. Third pitfall: telephone exchanges do not last for ever.

The removal from service of outmoded exchanges often accounts for a substantial share of the market open to switching equipment manufacturers.

Like any equipment, exchanges have not only a limited physical life but also an accounting life which, according to the rules of productive capital depreciation, determines the annual cost of capital invested in such equipment. This accounting life is fixed by national authorities and therefore varies from country to country [6].

The accounting life used to be estimated at between 25 and 30 years but, given the increasingly rapid obsolescence of switching systems, particularly of the older variety which were far less productive than the better performing modern types, it is now common to accept an accounting life of about 20 years [7].

However, regardless of the financial advantages or disadvantages arising from the abandonment of an exchange in a year other than the last year of its accounting life, telephone exchange equipment has to be replaced at one year or another. To give a rustic image of this situation, the stock of subscriber lines might be likened to stands of poplars which, in the hands of capable foresters, are cut down roughly every 25 years.

Analysts are chiefly interested in the number L of lines in service and, more particularly, in its *annual increment* ΔL. Indeed, the values of those two parameters say most about the development of a country's or agency's network, since all other network factors implicitly depend on the number of subscribers served.

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[5] Until 1980, the number of subscriber lines in service was usually the only value given in the statistics of telephone agencies. On the other hand, switching equipment suppliers are interested only in the stock of lines they have installed in an exchange: it is that value that they quote in their brochures. In 1980 the CCITT Plenary Assembly put matters right by introducing in its Recommendation "C.1" the notion of connection capacity in local telephone exchanges. This appears now as a heading in the ITU's Yearbook of Common Carrier Telecommunication Statistics (and is among the data which the ITU seeks but by no means systematically receives).

[6] In the model financial structure of telephone agencies, one essential factor in the "profit and loss account" is the importance attached to amortization, which is directly related to the equipment life adopted for accounting purposes.

In North America, the telecommunications industry and governmental authorities have paid much attention to this point in the early 1980s. Elsewhere it has been ignored even by the industry's economists. The reasons for this discrepancy are not hard to discern. For a private enterprise the amortization rate has a direct impact on company profits and on dividends distributed to shareholders. Both sides – the enterprise managers and the shareholders – are therefore keenly interested in the matter. For a state telecommunication administration, the situation is quite different. From its point of view, it is ultimately immaterial whether a sum of money is entered in the accounts under amortization or profits. One way or another, the whole of the sum in question will generally be used for investments.

In Canada and the United States, the subject of amortization calculations became in the early 1980s a highly controversial issue with legal overtones because of the accelerating rate of technological progress. Some large equipment (e.g. transit central offices) tended to become prematurely obsolete with the emergence of new generations offering much greater efficiency, so that it was often necessary to consider downgrading equipment before it has been amortized. Should financial decisions based on purely accounting considerations be allowed to stand in the way of technical reorganization? Should a company accept the risk of becoming "fossilized" in comparison with other sectors of electronic industry not subject to the restrictive accounting rules of the regulated system in force for the telephone industry?

[7] A recent 1989 "Services Directive" of the European Community in Brussels has decided that the national rules fixing the life to be respected for capital amortization of switching equipment should be liberalized. For the legal and financial authorities of the 12 EEC countries, this Directive will justify what has become a present policy of fast renewal of equipment. In some of these countries, e.g. France, for network modernization aimed at large ISDN implementation, a life of 15 years is now considered necessary for many switching installations and even realistic for all equipment of this type.

For switching equipment manufacturers, the key value specifically required for their market surveys is the number of lines installed or to be installed each year [8)] in a country, a figure which does not appear at first sight in world telephone statistics. Yet the market surveys carried out by each manufacturer, together with publications issued by consultancy firms (publications that are sometimes partly gleaned by technical journals, though usually with some time-lag) and a few fairly simple calculations make it possible to obtain a rough estimate of the annual world production of switching equipment for local subscriber lines. This we shall attempt to do ourselves in section 2 below.

1.5. *Fourth pitfall*: the subscriber lines and junction or long-distance circuit terminations in an exchange are not comparable items.

Although in a local exchange there is some homogeneity of specifications for subscriber lines, the same does not hold good for the switching equipment serving "junction" circuits (between exchanges in a multi-exchange area), far less for long-distance circuits. Here we have a field in which, depending on the characteristics of the circuits to be served – including their signaling characteristics –, the utmost diversity reigns.

There is a considerable price difference between the equipment serving subscriber lines and that serving circuits. A proportionality factor is sometimes adopted for their respective costs: hence the equivalence value often mentioned:

> "the price of a terminal equipment of a junction circuit or long-distance circuit represents roughly 8 times the price for a local subscriber line."

However, this equivalence must be treated with the utmost caution. Where it is to be applied for a transit exchange, even the way in which the number of incoming and outgoing lines is interpreted might also have to be viewed with circumspection.

An excellent example of the circumspection with which this equivalent ratio must be handled is given by a comparaison of the respective costs of a "local line unit" and of a "trunk line unit", taken from an exhaustive study of K. Hoffmann examining in [2] the expected growth of switching equipment in the DBP West German network during the period 1975–2025. During the years of this period, the money values of investments in local and trunk switching are nearly equivalent: they apply to the yearly average volumes of 1.8 million of local lines installed and of approximately 120 000 trunk line units. With these data, the cost ratio between a trunk line unit and a local line unit would be:

$$1.800/0.120 = 15$$

i.e. nearly the double of the most often quoted ratio, the one mentioned above.

2. Deployment of subscriber lines in service between 1960 and 1985

2.1. As in Volume I, in which we made an inventory of the state of the world telephone networks in the following eventful years:

1890 – the dawn of a telephone service still in its infancy (Volume I, pp.126–128),
1910 – a still limited and essentially manual service (Volume I, pp. 137–147),
1930 – beginnings of automation of big-city networks (Volume I, pp. 279–288),
1955 – advent of automation of national networks (Volume I, pp. 289–302),

we shall now repeat the exercise for the years 1960 and 1985.

The choice of 1960 will provide a link with the 1955 statistics given in Volume I, while the 25-year interval between 1960 and 1985 will offer an overall view of telephony development and, at the same time, will blur the fluctuations which occurred therein, mainly as a result of the economic "oil" crises of the 1970s.

2.2. Table A shows the "stock" of subscriber lines in service in the different continents and throughout the world for the two years 1960 and 1985. The average rate of annual growth of each stock over the 25 years considered is given in the end column.

[8)] It is to statistics related to exchange capacities in terms of equipped subscriber lines that we refer in the Chapters of this book when values of the production of a given type/family of switching equipment are quoted.

Table A
Stock of subscriber lines ("main telephone stations") in service in 1960 and 1985

Main Telephone Stations (in millions)

Sources (see Notes)	(1)	(2)	(3)	(4)
	Year 1985	Year 1960	Ratio 1985/1960	Growth Rate (average) per year
Continent (sub-continent)				
Africa	5.5	1.4	3.9	5 or 6%
America				
– North America	126.5	53.4	2.4	3 or 4%
– Latin America	19.5	2.9	6.7	8%
America	146	56.3	2.6	4%
Asia				
– Japan	45	3.5	8.2	9%
– Other Countries	30	2.3	13	11%
Asia	75	5.8	12.8	
Europe				
– Western Europe	131	24.2	5.4	7%
– Eastern Europe	34	5.6	6.1	7–8%
Europe	165	29.8	5.5	7%
Oceania	7.5	2	3.8	5–6%
World	399	95.3		

Note. *Sources of Table A*
(1) Data (1985 year) from Siemens Statistics.
(2) Data (1960 year) from the ATT "The World's Telephones": data given in "telephone stations of all kinds", and converted in "main stations" in service by applying the percentage factor:

$$\frac{\text{“main stations”}}{\text{“telephone stations”}}$$

given in this publication for the most important countries.
(3) The use of two different sources to obtain the 1960 and 1985 data is due to the non-existence of the Siemens Statistics in 1960 and to the discarding in 1984 by ATT of its publication "The World's Telephones". The data used by these two sources are consistent with (and more extensive than) the ones that have been published in the ITU statistics under a succession of different names and formats. (Publication by the ITU of the " Yearbook of common carrier telecommunication statistics" began only in 1971).
(4) In column 4, g is the average growth rate per year during the period 1960–1985.

Analyses covering far shorter and above all much more recent periods have appeared in excellent articles, some of which have been published somewhat recurrently in the ITU's Telecommunication Journal (references [2–4]). Readers interested in this sort of analysis might usefully refer to them and to forthcoming articles from the same sources, which are as manna from heaven to the switching specialist or telecommunication economist.

Compiling statistics as the ITU do is certainly tantamount to a charitable work. The by no means easy task of extracting from them the characteristics trends of a particular development, drawing lessons from them and working out forecasts is an even more useful, not to say essential, exercise.

2.3. As indicated in section 1.4 above, rough estimates of the market open to switching equipment manufacturers, in so far as it relates to the production of local subscriber lines, can be worked out from the figures in Table A, taking 1985/1986 as target reference years, for *a model exercise of methodology*.

It is a well-known fact that the demand for local subscriber lines is now almost saturated in many highly-industrialized countries. When virtually every home has its own subscriber line, as is becoming the case in practically all developed countries, one of the main markets open to the manufacturers of public telephone switching equipment becomes the "transit exchange" sector. The country's or agency's chief parameter is then no longer the number of subscriber lines but the traffic generated by them [9].

2.4. To get back to the public switching markets for subscriber connections, our rough estimate should distinguish between two items of potential demand existing in 1985, namely:

a) the replacement of exchanges which have come to the end of their life. This market is not easy to assess accurately since it depends in each country on subjective decisions of the telecommunication agency(ies). With some approximation, it can however be considered as related to exchanges installed, say, 25 years earlier;
b) the expansion of subscriber connection lines.

There is now a whole set of cases reflecting the situation in the different countries or sub-continents:

i) those with developed telephone networks in which factor a) is predominant and,
ii) conversely, those developing (sub-)continents, where factor b) accounts for the bulk of the potential market.

[9] Measured in Erlangs, this parameter starts to stand out in network development forecasts published by some administrations in the economically more developed countries (see [2] by way of example).

For calculation purposes, therefore, the situations in the different sub-continents must be broken down into matrix elements as shown in Table B: for those which fall into category i), factor a) must be taken into account and, for those in category ii), allowance must be made for factor b), having regard to the most recent rates of growth in the telephone network rather than to the very different rate observable over the lengthy period from 1960 to 1985.

2.5. The above evaluation is mentioned more to offer a methodological example rather than to provide an accurate value of the size of the potential market for local exchanges lines production in 1985/1986. Moreover, that market accounts for only 35–40% of the turnover of switching equipment manufacturers, which also includes:

- the production of transit exchanges and the share of "combined" (local/tandem) exchanges for serving junction and long-distance circuits;
- the production of switching equipment for private telephony (PABXs, etc.).

2.6. The calculation worked out in Table B is a pure exercise of forecasting theory. Results observed may differ from the forecast data!...

Just as in the case of agricultural harvests and more particularly of the vintage wines familiar to writers on gastronomy, so have there been bumper years and less auspicious for switching equipment production, reflecting:

- overall economic conditions. For instance, orders placed by the national Administrations of many European countries between 1974 and 1976 were affected by the budgetary restrictions imposed by the different Finance Ministries at the time of the first oil crisis of the 1970s;

Table B

A *theoretical model of forecast* of the market offered to switching manufacturers for the production of "Direct Exchange Lines" (DELs). *(A model for the period 1985 / 1987)*

(Values expressed in millions of subscriber lines, with M = main station lines = direct exchange lines (DELs), and g = % growth rate for the two periods 1983/1984 and 1984/1985

Column Sources Year	(A) (1) 1960	(B) (2) 1985	(C) (3)	(D) (4)	(E) (5) 1986
Item	M (1960) (replacement of 1960 lines)	M (1985) existing	g (in%) for periods: –1983/1984 and –1984/1985	New M for new subscribers (B) × (C)	Σ of new M [values of (A) + (D)]
Continent (sub-continent)					
Africa	0.11	5.5	10%	0.55	0.7
America					
– North Am.	3.0	126.5	3%	3.8	6.8
– Latin Am.	0.15	19.5	9%	1.7	1.9
Asia					
– Japan	0.5	45.0	4%	1.8	2.3
– Other countries	0.4	30.0	13%	3.9	4.3
Europe					
– Western	1.5	131.0	5%	6.5	8.0
– Eastern	0.4	34.0	4%	1.4	1.8
Oceania	0.14	7.5	7%	0.5	0.6

World production = 26.4, i.e. in round figures, 27 Millions of lines.

Sources of Table B:

(1) As explained in Volume 1 (Box A, p. 284), it can be considered that there is an approximate equivalence between the figures for the number of "installed automatic lines" and those published (by AT & T) for "automatic telephone stations of all kinds". The incremental annual value L of these latter is taken out from the AT & T "The World's Telephones" publication (1960 issue) [10].

(2) The values of M (number of main stations) are the ones quoted in the preceding Table A.

(3) The growth rates, g, for M during the last years (1983, 1984) preceding the 1985 year considered are those quoted by P. Luhan in his study [1].

[10] An initial approximation only, because the "M" for 1960 masked the replacement in 1960 of the 1930–1935 generation of exchanges and therefore takes no account of the number of subscriber lines installed in 1960 to replace outmoded exchanges. The difference will, however, be very slight in view of the small number of subscriber lines in the 1930–1935 generation of exchanges.

- the impact of technological change.

For example, 1986 (the "target" year in Table B) is to be regarded as a year of exceptional production by North America's switching industry, owing to the large-scale replacement of the relatively low-capacity and principally Strowger-type electromechanical exchanges by the new generation of electronic exchanges (ESS 5, DMS 10 and 100). Price-wise, these new types of cental office were highly competitive in catering for local network line capacities of the order of 2000–8000 lines. In addition, they held out numerous advantages as regards both services offered to the subscribers and operational features. Hence, the rapidly accelerated pace of replacement of exchanges of such capacities in 1985 affecting models that had been in service for 18–25 years or more.

This explains the obvious discrepancy between the numbers of North American lines:

- actually produced in 1985 as a result of the accelerated replacement of the earlier generation of exchanges, scoring a record number of 10 million lines [3];
- given in Table B, i.e. 6.8 million lines: indeed, this figure was based on the replacement solely of 25-year-old central offices.

The exceptional discrepancy explained here in no way vitiates the estimate given in conclusion of Table B, which represents no more than a possible order of magnitude for the production of telephone switching equipment for local networks. Whatever might be regarded simply as short-term fluctuations must be resolutely disregarded whenever such estimates are made.

3. A prodigious development of long-distance and international traffic in the 1960–1985 period

3.1. The period from 1960 to 1985 witnessed a sizeable increase in the world "stock" of telephone subscriber lines. However, what marked the period even more was the extraordinary expansion of the long-distance service and, to an even greater extent, international/intercontinental traffic. While the subscriber line stock underwent an average growth rate of about 5% during that period, long-distance national traffic expanded at about a growth rate 10–12% and international traffic, of 20–25% [11].

3.2. There were two basic reasons for this phenomenon:

- the introduction of transmission facilities (of often new types) with a higher performance which made for considerable reductions in costs and tariffs for long-distance service, thus triggering a co-relative increase in demand. As examples of these transmission facilities: existence of higher-capacity radio-relay links, the emergence of optical fiber cables, etc.. And for intercontinental relations: transoceanic submarine cables and satellite links;
- the automation of long-distance traffic, which virtually brought people within immediate finger-tip range even if they were at opposite ends of the earth.

3.3. International traffic and the transmission facilities for handling it are analyzed in detail every four years by the CCIR-CCITT Plan Committees of the ITU. Tables C and D show the major events concerning the introduction of intercontinental transmission facilities.

These two Tables (Table C for submarine cables, Table D for satellite systems) are based on "Plan books" issued by ITU after meetings of Plan Committees and reports on them published in the ITU Telecommunication Journal.

[11] see in Chapter XI-2 the Table 1 covering the relative growth of AT&T revenues corresponding respectively to local services and long-distance services.

Table C
Major events concerning the introduction of transoceanic intercontinental submarine cable routes for the telephone service [4–6]

Main cables year	name	between	Telephone circuit capacity
Transatlantic routes:			
a) *North Atlantic routes:*			
1956	TAT 1	Clarenville, Newfoundland and Oban, Scotland	48 *
1959	TAT 2	Clarenville and Penmarc'h, France	48 *
			* note: no more in service in 1985
1961	CANTAT1	Newfoundland and Oban	80
1963	TAT3	Tuckerton (USA) and Widemouth (UK)	138
1965	TAT4	Tuckerton and St-Hilaire du Riez (F)	138
1970	TAT5	Green Hill (USA) and Conil (Spain)	845
1974	CANTAT2	Widemouth (UK) and Halifax (Canada)	1840
1976	TAT6	Green Hill (USA) and St-Hilaire du Riez (F)	4190
1983	TAT7	Lands End (UK) and Tuckerton (USA)	4200
1988	TAT8	USA-UK-France (optical fiber cable)	16000
b) *South Atlantic routes:*			
1969	SAT 1	Portugal–South Africa	360
	(Greenland)	(with a UK–Portugal extension)	640
1973	Bracan	Brazil–Canary Islands	160
1977	Columbus	Venezuela–Canary Islands	3240
1982	Atlantis	Portugal–Dakar (Senegal	2580
		+ Dakar–Recife (Brazil)	1380
		+ Dakar–Abidjan–Lagos	
c) *Transpacific routes:*			
1957	Hawaii 1	Honolulu–California	51
1963	Compac	Vancouver (Canada) and Australia + New Zealand via Hawaii and Fiji	* no more in service in 1985
1964	Hawaii	(see Hawaii 1)	143
1964	TPC 1	Hawaii and Tokyo + Manila	143
197x	Seacom	Guam–Hongkong and Singapore	
1974	Hawaii 3	(see Hawaii 1)	845
1975	TPC 2	(see TPC 1)	845
1984	Anzcan	Canada and Australia + New Zealand	
1986	TPC 3	(see TPC 1)	3780
d) *Indian Ocean route:*			
1984–	Sea-Me-We	South-East Asia, Middle-East,	1080
1986		Western Europe	2580
e) *Other routes:*			
Plus a dozen (or more) of submarine cables criss-crossing:			
– the Mediterranean sea (the first laid in 1961)			
– the Caribbean area (the first laid in 1963)			

In April 1989, the first optical-fiber cable to cross the Pacific Ocean and link the United States and Japan went into service. Providing 40,000 circuits, it was a US $700 million joint-venture of 30 telecommunication companies, the largest being the American AT&T and the Japanese KDD.

Table D
Major events concerning the introduction of intercontinental satellite links [7–10]

1. *Low-altitude orbiting satellites:*
In July 1962, Telstar 1 was put into service by AT&T, acting in cooperation with some Western Europe countries for the provision of their satellite earth station. Telstar was the first active telecommunications satellite carrying antennae and amplification equipment. It opened the age of space telecommunications and "mondovision".
In April 1965, the USSR launched MOLNYA 1, its first telecommunications satellite which provided telephone circuits between the major cities of USSR and TV program distribution throughout the country. Molnya 1 was followed in 1971 by MOLNYA 2 which offered an international telecommunication system operated by the INTERSPUTNIK international organisation.
2. *Geostationary satellites:*
In April 1964, the USA placed the first telecommunications satellite in a geostationary orbit, the SYNCOM 3 satellite, conceived by H.J.Rosen of Hughes Aircraft. The first launching and use of a geosynchronous satellite happened in 1963 when NASA successfully demonstated television transmission through a SYNCOM 2 satellite, built also by Hughes Aircraft.
Before the launching of SYNCOM, the USA Congress had passed the Satellite Communications Act of 1962, which authorized the formation of the COMSAT, a private American company chartered to establish a global commercial communications network in cooperation with other countries.
In August I964, the International Telecommunications Satellite Organisation (INTELSAT), with originally 11 participating countries, was established in Washington (D.C.). A geostationary orbit was chosen for the first international INTELSAT telecommunications satellite. It was the small but famous Early Bird, brought on position over the Atlantic in April 1965. Early Bird (also registered as INTELSAT 1) provided a capacity of 240 telephone circuits, or alternatively the possibility of a regular transatlantic TV transmission.
In October 1966, the first INTELSAT II was succesfully launched, the first of a series of three of the same type, with the same capacity of 240 telephone circuits or one TV channel as the former INTELSAT I, but providing a common and multipled access to the four European earth stations located in France, Germany, Italy and UK.
The first INTELSAT III was launched in 1968. Satellites of this type were positioned over the three main regions to be covered by the Intelsat system, i.e. the Atlantic, Pacific and Indian Oceans. By 1969, a world telecommunications coverage via Intelsat satellites was obtained.
Then came the following generations of Intelsat satellites: INTELSAT IV (1971), IV-A (1975), V (1981), VI (I986) (the first to offer TDMA = Time Division Mutiple Access), each of these types offering an always larger expansion of the telephone (or TV) channels capacity provided.
"In 1983, the Intelsat system provided global satellite communications for more than 130 countries, through networks consisting of some eight operating satellites and approximately 530 earth stations. The capacity of the Intelsat system (was) to increase by a factor of 4 over the next ten years... In addition, the Intelsat system was leasing transponders to 23 countries for domestic satellite service. It was the system which provided essentially all of the world's transoceanic television." [9].

3.4. The results of the launching of so many telecommunication satellites and the laying of so many submarine cables can be summarized by Table E giving the number in 1987 of intercontinental circuits on the various traffic relations.

Table E (from [11])
Intercontinental telecommunications worldwide traffic 1987

	Number of Circuits
Europe–North America	24000
North America–Asia + Pacific	8000
Europe–Asia (except Mediterranean bordering countries) + Pacific	7800
Europe–North Africa + Mediterranea bordering countries	5600
North America–Central America + South America	5300
Europe–Central America + South America	4900
Europe–Africa (except North Africa)	4750
North America–Africa	650
Others	3000
Total	64,000 intercontinental circuits

4. Automation of long-distance traffic

4.1. Telephone exchanges in the major urban metropoles were automated in the 1920s and particularly in the 1930s. Following the Second World War, this automation process continued throughout the developed countries in both the 1950s and the 1960s. The general introduction of automatic services to local subscribers was of course matched by the automation of national trunk services.

Table F (taken from Volume I, pp. 22–23) shows the years in which 100% automation was reached or nearly reached in 1977, a goal harder to achieve when a country is large in size and population.

Table F
Countries with full automation of their telephone network

Country (only countries with more than 100 000 main stations)	Year of complete automation of the national network	Countries practically in asymptotic situation of full automation	
		% of automation in 1978	
Switzerland	1959		
the Netherlands	1962	Australia	97%
Germany (FRG)	1966	Canada	99%
Belgium	1970	France	99%
Austria	1972	Greece	99%
Sweden	1972	Japan	99%
Denmark	1973	Mexico	99%
United Kingdom	1977	United States	99%

4.2. Provisioning of automatic national trunk services was followed in Europe by the age of the *international automatic service* and, a few years later – this time in all developed countries of the world –, by the intercontinental automatic service. The following details of this process are worth mentioning.

Thanks to the drive of Marc Lambiotte [12], the then Chairman of the competent CCIF/CCITT Study Group for "automatic telephone service", this international service was first introduced to the public from Belgium:

- in 1957, opening of the "Belgium to Paris area" relation,
- and in 1958, opening of the relation in the opposite direction.

The latter event, widely celebrated like the former, coincided with the opening of the Brussels 1958 World International Exposition. The telecommunication pavilion there, organized by the RTT Belgian Administration, was fitted with public booths which, by way of demonstration, offered free automatic access to subscribers in five foreign countries of Europe; as an attraction this was much appreciated by the public and enthusiasts were soon forming orderly queues outside the booths.

4.3. From the mid-1960 onwards, the international automatic service spread like wildfire in Europe from one international relation to another. However, this was not before the CCITT had established the codification of what is named a "country code" [13], the worldwide standard prefix giving access to the network of a foreign country. Its codification at the world level was obtained at the Geneva 1964 Plenary Assembly of the CCITT and constitutes one of the almost intangible foundations on which the world's telephone network and service are based.

[12] He shortly afterwards became Director-General of the Belgian Telegraph and Telephone Administration (RTT).

[13] For instance, 1 for access to the North American continent (United States and Canada), 33 for France, 39 for Italy, 44 for the United Kingdom, 49 for the Federal Republic of Germany and 81 for Japan, etc.

4.4. After the introduction in 1963 and 1964 of the semi-automatic service on the North-Atlantic route [14], intercontinental automatic service made its appearance in the beginnings of the 1970s and gave rise to a dramatic expansion of the intercontinental traffic. Most of the less developed countries, connected by satellite circuits to intercontinental centers in Europe, United State or Japan, had also soon access to this type of service.

[14] see Chapter X-2, under section 7.

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CHAPTER XI-2

ANALYSIS OF THE DEMAND FOR TELECOMMUNICATIONS DURING THE 1960s AND 1970s

1. The market demand for telecommunications in the 1960s and 1970s was marked by three essential features:
- predominance of the traditional telephone service;
- the increasing share taken up by business traffic;
- considerable expansion of data transmission, at that time a new service.

2. Predominance of the traditional telephone service

2.1. The "Plain Old Telephone System" – the "POTS" [1] – , operated in the most traditional manner, held [2] absolute predominance. Other services operated by carriers and existing in parallel with the telephone service, – initially, only the telegraph and telex services, and, later, data transmission – , accounted in the 1960s for less than 5% of total carrier earnings.

Since the end of World War II, telephone enterprises had been concentrating on providing a more or less satisfactory service to meet the public clamour for access to the telephone. In many countries it had been necessary to continue and complete the reconstruction of networks destroyed as a result of war damage. Efforts to expand the network were often disappointing, particularly in countries where State Administrations existed, for the budgetary restrictions imposed as a result of government or parliamentary indifference made it impossible to meet the public demand.

2.2. In Japan, autonomous management enabled NTT, the enterprise operating the national telecommunication service, to circumvent such constraints.

Fig. 1, showing how the Japanese telephone network expanded between 1952 and 1980, offers us the finest example of the race which took place in the 1960s and 1970s to meet demand.

A point of inflexion, so characteristic of the logistic curves familiar to telecommunication economists, is discernible in the above figure. It means that the potential demand is about to become saturated in a not too distant future. As the Japanese-drafted note beneath Figure 1 suggests, the point of inflexion might have been reached in 1977. NTT's subsequent plans aimed not at quantitative expansion but at diversification of the products and services offered to users.

2.3. Making full allowance for scale, the pattern of telephone service development in the different countries was similar to that given as an exemplary model, though there was certainly a

[1] The acronym POTS first appeared in an article by Paul Fleming in "Telephony". It is so homely and practical that it has come into universal usage in English-language technical literature.

[2] The telephone service holds again in the 1980s this absolute predominance in the earnings of telecommunication carriers: in 1987, a share of 87%, according to [1].

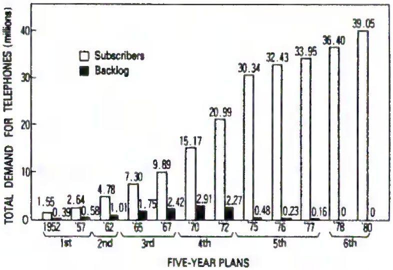

Fig. 1. Changes in the number of Japan's telephone subscribers and backlog. Along with the telephone network expansion, the principal goal in NTT's range program was to cut down the unfilled backlog of telephone applications and to realize nationwide subscriber dialing. This goal had almost been met by the end (1977) of the 5th five-year program. The next objectives after the completion of this program were to improve the transmission quality of telephone communication and to supply a variety of new services.

less aggressive approach than in Japan and therefore some time lag [3] [4].

From all this, it may be concluded that it was only towards the end of the 1970s or just before the 1980s that users and the public in general started to demand a more "intelligent" and more diversified telephone service.

3. Preponderance of business traffic

3.1. Although industrial and trading companies account for only a small proportion of all telephone subscribers, the traffic they generate is disproportionately great. It may be claimed that in the industrialized countries business lines account for less than about 15% of all subscriber lines, whereas earnings from the traffic they carry amount to some 50% of the total receipts of the telecommunication enterprise [5]. The share of receipts from business traffic is even greater in the developing countries [6].

There is nothing surprising about all this: we all know how readily the telephone is used in business and, incidentally, most of its traffic occurs at peak hours and is therefore charged at the highest rate.

3.2. It is in long-distance traffic and more particularly in international traffic [7] that the peculiar growth of business traffic occurs. The 1970s were typical in this respect: in the United States, that was the decade in which the Bell System's earnings from long distance traffic – carried on its Long Lines – exceeded earnings from local traffic within its Bell System companies (see Table 1 [5]) [8]. And it was precisely corporate business which generated this very high

[3] Thanks to the pre-1945 situation, the curve showing expansion of the subscriber line stock in some countries (North American continent, United Kingdom and Sweden) slopes much more gently than the Japanese curve. France was another exception, with a very flat expansion curve until the mid-1970s, followed by a very rapid upward sweep over the following ten years.

[4] Research into user demand started only in about the mid-1960s. The CCITT took the initiative in 1968 by publishing its first "Economic studies at the national level in the field of telecommunications" (known as the "GAS 5" Handbook) which was almost entirely devoted to analysing that demand. The results given in that 1968 publication and the other GAS 5 Handbooks published every four years were combined with others derived from World Bank studies in the basic reference work on telecommunication economics entitled "Telecommunications and Economic Development", by R.J. Saunders et alia [3].

[5] An American magazine article in 1985 stated that " in lower Manhattan, 0.33% of New York telephone customers generated 33% of the Telephone Company revenue !..".

[6] Many studies have been made of the breakdown of total subscriber lines according to the socio-economic nature of the subscribers and of the corresponding receipts. See in particular L. Engvall [4] reporting on this dual breakdown (residential/business) in the developing countries according to their level of economic development and standard of living.

[7] After the 1960s the annual growth rate of the international service oscillated between 20 and 30%, a particularly high rate which is explained by the opening of the automatic international service and the existence of intercontinental links using submarine cables and satellites.

[8] "Long-distance traffic was increasing at a yearly rate of about 10%, double the rate of increase for local traffic."[6]

Table 1
Evolution of AT&T revenues (from [5])

Year	Local service	Toll service
1955	3.1	2.1
1960	4.6	3.0
1965	6.0	4.6
1970	8.5	7.9
1975	14.0	13.9
1976	*15.6*	*16.0*
1977	17.0	18.0
1978	18.7	20.7

Sources: American Telephone and Telegraph Company, Bell System Statistical Manual: 1950–1977, May 1978, p. 202. Revenue Data for 1978 taken from American Telephone and Telegraph, 1978 Annual Report.

Note. 1976 is the year (in italics) for which AT&T toll service revenues began to exceed those of local services.

rate of growth in long-distance traffic. The financial success of AT&T's Long Lines eventually created a backlash and it was to the mounting pressure from business circles that the process of dismantling the Company's monopoly for handling long-distance and international traffic in the United States was later attributed.

3.3. Business and industry are therefore major customers of the telecommunication enterprises. Consequently they are demanding and, knowing full well how to make best use of the many facilities offered to them, they are attentively nursed by telecommunication agencies [9]. The ordinary public telephone service only partly meets their needs and they are particularly anxious to secure direct and in some cases even transcontinental links in the form of leased circuits. In the United States and later in every other market economy country, the larger corporations and particularly the multinationals are thus constituting veritable private networks between their different offices.

3.4. Businesses and government departments are also the almost exclusive users of what was in the 1960s and 1970s the main competitor of the telephone service, namely the telex service. The slogan of the Bundespost in the late 1970s was "A telephone in every home but also a telex line in every business".

3.5. Another aspect of the demand from business circles concerns access to distant computers and therefore the need for data transmission circuits. Here again business, and to a lesser extent government departments followed at an even greater distance by universities, were the almost exclusive customers for data transmission. This service, which was introduced in the mid-1950s, was for years effected essentially over special leased telephone circuits covered by specific maintenance provisions.

4. Considerable expansion in the demand for data transmission in the 1970s

4.1. The demand for data transmission increased spectacularly in the 1970s, far faster than for the telephone service [10]. This increased demand may be explained by the combination:
- on the one hand, of advances made in computer technology and to an even greater extent the general spread of computers themselves, and
- on the other hand, of the higher performances of both the terminal equipment (modems) and the networks used for data transmission.

4.2. The development of data transmission and the introduction of packet switching into the service, mark significant stages which have foreshadowed the trend towards the digitization of telecommunications. Even if the initial approach was in the opposite direction, so to speak, since the data bit streams were cast in the analog

[9] "Each passing year we are accelerating the transformation of a network that not so long ago provided a more or less uniform service to all its customers to one that not many years hence will serve not two of them alike." (C.L. Brown, Chairman of the AT&T Board, in his 1979 Annual Report).

[10] While not particularly significant, the rates of growth of new services introduced from scratch are always very high. In the case of data transmission, the most interesting phenomenon was the persistent continuity of a high long-term growth rate.

Box A

Activities of the CCITT in data transmission

1. General

It was in 1956 that the CCITT first faced the problem of "What general characteristics should be standardized to permit international transmission of data?" (CCITT Question 43, 1956).

In 1960, a Special Study Group (now Study Group XVII) was set up to deal with this subject.

During the 1960s studies of data transmission in the CCITT concentrated on the use of the public telephone and telegraph networks as a means of providing such a service.

In the early 1970s the CCITT began to study new public networks dedicated to data services in order to meet the stringent requirements for rapidly evolving data processing services that the existing telephone and telegraph networks might not be capable of satisfying them in the future. In 1972, a new CCITT Study Group (S.G. VII) was formed for the specific purpose of studying one or more public data networks.

2. Data transmission over public telephone (and telegraph) networks (CCITT V series Recommendations)

In the beginning of the 1980s the telephone network was accommodating most of the data transmission traffic, either on a normal call-by-call basis (switched telephone network) or by providing leased telephone circuits. There are many reasons for this, the main ones being:

- the widespread availability and the ubiquity of the telephone service,
- a telephone network which can transmit data at a wide range of speeds.

A range of speeds had been standardized by the the CCITT for data transmission over telephone circuits. It is based on a geometrical progression and begins with 300 bit/s, goes through the steps 600, 1200, 2400, and 4800, to reach 9600 bit/s for point-to-point 4-wire circuits. Corresponding to each of these speeds, there is a particular type of modem the main characteristics of which were CCITT standardized.

In the course of time and in order to take advantage of the introduction of higher-performance devices made possible by integrated circuits, the standards for these modems have been changed on a number of occasions and significant improvements have been achieved as regards compatibility between different makes of modems.

The range of transmission speeds for data transmitted over the telephone network had, however, and already for a long time, exceeded that of a telephone circuit. As from 1968, data transmission using the bandwidth (60 to 108 kHz) of a group of 12 telephone channels was introduced.

3. Public data networks

In 1968 and, above all, since 1972, the CCITT began its studies on the creation of public networks to be used exclusively for the transmission of data. CCITT was an initiator in this field, a completely unexplored territory.

Public data networks have to offer their users:

i) a wide choice of data transmission speeds,
ii) a wide choice of special facilities,
iii) extremely fast call-set-up times.

The variety of options offered in i) and ii) above has been supplemented by a third range of options relating to the operation modes of the data transmission system, i.e. "asynchronous" mode, synchronous mode and packet mode:

a) the "asynchronous" mode, the classical start-stop mode which should continue to be usable in gaining access to the public data network from the user terminal.
b) the synchronous mode, characterized by a time-division multiplex in which the meaning of the information is defined by the point in time at which it occurs.
c) the packet mode, also corresponding to a time-division multiplex but with each data information identified by a label: "framing" is used and packets are assembled and disassembled according to label.

Despite the multiplicity of all these options, a coherent body of CCITT Recommendations (the "X" Series) has been established. It offers users a great freedom of choice while at the same time strictly standardizing all the conditions, procedures and protocols for the transport of information over the public data network. Tables 1 and 2 indicate some of the essential possibilities offered to users.

Table 1
Data public network (CCITT Recommendation X.1)

Class	Operating mode	Bit/s speed
1 and 2	start-stop	50–200 300
3 to 7	synchronous	600–2400–4800–9600 and 48,000
8 to 11	packet	2400–4800–9600 and 48,000

Table 2

Data public network. Some examples of user services (CCITT Recommendation "X.2"):
- closed user group
- calling and called line identification
- redirection of calls
- connect when free
- reverse charging

mould of telephone circuits at both their input and output, with modems (modulators-demodulators) having to effect digital/analog conversions and vice-versa.

The introduction of the first circuit-switched and packet-switched *data networks* in the mid-1970s [11] was to restore to data communications their intrinsic bit-transmission character [12], i.e. a digital and no longer an analog character.

4.3. A whole series of improvements to give modems a higher performance, particularly as regards their transmission speed, was implemented in the 1970s. In addition, new data transmission modes including packeting were introduced.

The different phases of development can be followed by referring to CCITT studies and the order in which they were made, as very briefly outlined in Box A besides which merely reflects, although fairly accurately, the progress made in the different countries. Admittedly, some data transmission systems had first to be built (usually in the United States) and made known before the subject could be raised at the international level

[11] The provision of data-only networks which no longer used surplus telephone or telegraph circuits was motivated by reasons that had to do with the nature of data traffic itself, the characteristics of which differ greatly from those of telephone traffic, as described in Chapter IX-2, section 6.

In telephone, calls usually last between one and three minutes in the national service and between three and six minutes in the international service. Call-set-up times – the "post dialing delays (PDDs)" - which vary greatly depending on the structure of the national network concerned, are measured in seconds or, in some countries, in dozens of seconds.

In data transmission, when access to a computer is needed, with many data transmission consisting of data bursts of only a few seconds, PDD user requirements are far more exacting.

[12] or other modes, e.g. a ternary mode for transmitting the bit elements. The furthest level of digital encoding includes "spread spectrum" techniques in which the theoretically indivisible bit is broken down into a finite number of sub-elements, the wanted bit being restored upon reception even if some of the sub-elements were meaningless during transmission.

within the CCITT. On the other hand, however, CCITT decisions on standardization did sometimes have an immediate impact on the expansion of this or that data transmission mode, as the example of the famous standard protocol X.25 [13] witnesses.

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[13] CCITT Recommendation X.25 defines the interface between DTE (data terminal equipment) and DCE (data circuit-terminating equipment) for terminals operating in the **packet-mode**.

CHAPTER XI-3

CHARACTERISTIC FEATURES OF THE TELEPHONE OPERATING AGENCIES STRUCTURES IN 1960 AND 1985

1. Some permanent specific features of telecommunications enterprises

1.1. There are a number of permanent specific features common to the economic structures of all telecommunication operating agencies, – hereafter referred to as "TOAs" and either State Administrations or Private Operating Agencies:

- similarity of the equipment series required and the implications of the need for "heavy" (i.e. very costly) equipment;
- similarity of accounting procedures, with very strict similar rules applied more or less universally in all countries, (in fact, very often these rules are not so much imposed as simply traditional accounting habits that have been quasi-religiously maintained, relics from a distant past);
- the fact that these enterprises operate almost in a "closed cycle", using only a minimum of intermediate consumer goods and depending essentially on the two "production factors: "K" (costs of the capital) and "L" (labour costs).

1.2. Other and no less essential characteristics should also be emphasized:

a) TOAs operate as legal or *de facto* monopolies [1]. Unconcerned with the problem of competition, their only economic target is to adjust production capacity in line with demand (which is partially dependent on the quality of service).

b) Nowadays, and particularly in developing countries, this demand is itself almost insatiable (although in the most developed countries the growth rate tends to decline because of a saturation effect, when, for example, nearly every household is connected to the telephone network).

c) The demand is also well known. Demand estimates may now be made by fairly straightforward traditional methods or by highly sophisticated techniques, but the results obtained are sufficiently reliable in either case.

d) For both social and political reasons, the prices of TOA's products can change only progressively, slowly and within very narrow limits [2].

1.3. The industrial policy of the TOAs is therefore based on a very simple approach and may be virtually reduced to the pursuit of two objectives:

- to promote the investments needed for the development of the production,

[1] This was true in all countries until early in 1984, when it ceased to apply in the United States, as a result of the move towards AT&T's divestiture, which had been under way in that country from the early 1980s. Although the United States case has to be stressed here as a capital exception to a monopoly situation, with also a mention of an opening to (limited) competition in Japan and the United Kingdom, the monopoly situation remains the rule in all other countries, and particularly in developing countries.

[2] This is true for the bulk of the TOA's products, i.e. the traditional "basic services". It is less true for "new services" that are launched by TOAs for a variety of applications and each year in great numbers, e.g. in 1988, 30 were launched in the United States by the RBOCs and 15 in France by France Telecom, etc.

– to ensure the maintenance or improvement of service quality.

(The simplicity of this approach contrasts with the complexity of the industrial strategies of ordinary enterprises facing problems of competition and widely fluctuating markets.)

All a TOA is concerned with, therefore, is to carry out a production process as efficiently as possible, with the benefit of highly stable conditions:

– a clearly defined market, with a reliable estimate of the growth of demand;
– equally well established prices for its products.

"More equipment, and equipment with better technical and cost performances", – no need for any theorizing –, that was the goal constantly pursued for over a century by TOAs and their managers [3]. Equipment meant circuits and exchanges ("central offices"). It was essentially these items that were recorded in the "Annual Reports" of a TOA, or in the detailed statistics it provided. It was increases in these figures that were highlighted, sometimes with no lack of pride.

It has to be admitted that when the demand exists and is ready to respond to the supply, it is legitimate and natural that the main aim in the first place should be to set up infrastructure, i.e. to *produce* telecommunication facilities. A policy in which production is everything, therefore ...

However, the production of telecommunication facilities (main subscriber lines, exchanges, long-distance circuit mileages) often used to take precedence over the need to manage them efficiently. Hence the significant shortcomings that have often been noted in the way they are run:

– lack of alternative routes when particular long-distance lines are congested although others may be carrying little traffic;
– sizable percentage of an exchange's subscriber lines not used (over and above the reserve normally allowed for when installing or extending an exchange);
– slow clearance of faults,
– complete failure of the administration to adopt any commercial policy (e.g. continuance of a charging policy with a single tariff for long-distance calls whether at peak traffic times or not, without taking into account traffic congestion)
– etc.

Those are just a few examples of a situation which existed just recently in many telecommunication administrations of the countries regarded as industrialized. And it is still the case, and in fact usually so, for many TOAs in developing countries;

2. Telephone operating agency structures in the 1960s

2.1. *Immutable structures since half a century*

In the 1960s as in the 1950s, the TOAs' structures were in all countries firmly set and extremely stable. The mode of being of all such bodies and their statutes went back half a century or more. The agencies themselves had not only continued virtually unchanged but would seemingly remain so for ever [4),5)].

[3)] Sometimes with quite meager and disappointing results when they were faced with an accumulation of financial obstacles, generally for State administrations as a result of budgetary restrictions imposed by parliamentary or governmental authorities, more concerned with balancing the general State budget than promoting the development of telecommunications.

[4)] A typical example is to be seen in Germany. After the turmoil following the end of hostilities in the Second World War, the two States which came into being – i.e. the Federal Republic of Germany (FRG) and the German Democratic Republic (DDR) – both retained the same type of State-administration structure which had existed before the war, albeit under a slightly different name.

[5)] The one exception was Japan where new operating structures based on an American model were established after the Second World War: creation in 1952 of NTT (Nippon Telegraph and Telephone), a government-owned and independently operated corporation supplying Japan's domestic requirements, and creation in 1953 of KDD (Kokusai Denshin Denwa Co.), a semi-governmental organisation covering international services.

Both the staff of the TOAs and their users, i.e. public opinion and, worse still, the politicians who were supposed to represent it, saw the agencies as majestic monuments which by virtue of long historic tradition would live on within their immutable structures, ones which nobody at the time would dream of attacking or even dare to suggest that they might benefit by a hint of cautious reform.

2.2. *Administrative unwieldiness due to centralization*

The TOA organization was strictly hierarchical and in all respects comparable to a military model. In the capital of the country or territory served, discretionary power lay in the hands of a directorial general staff, albeit one subject to the budgetary and credit constraints imposed by political authorities, while throughout the territory there were operational services, the smallest details of whose procedures hung on decisions handed down from above.

2.3. *Historical reasons*

In Europe, the TOAs status as State telecommunication monopolies has two distinct origins:

- The first one, purely historical and dating from the 1890–1910 period, was a political judgment of these years that private organisations for the telephone service had failed and that it was better to integrate this service into the Postal administration which was already operating the telegraph service.
- The second one stems from the special position of telecommunications with regard to defence and national security. This last factor is certainly the most important to explain the difference between the TOA status in the North America continent, a haven of peace, and in Europe, a continent of political conflict and wars until the 1960s.

2.4. *Telephone Agencies living in isolation*

Another characteristic feature of national telephone agencies in all countries (European or not-European) during the 1950s and 1960s was the isolated lives they all led. Indeed, what went on beyond their domestic frontiers was known to only very few of the agency managers, let alone their staff [6]. Virtually the only international meetings at the time were those held under the auspices of the ITU organ known as the CCIF, which in 1956 became the CCITT. Participation in the meetings of those bodies was, however, relatively limited, generally confined to a few high-ranking personalities and, until the late-1970s, with a large predominance of European participants.

From the 1960s, this highly parochial character of the national telephone agencies was completely altered by two factors:

- the first, of a completely pragmatic nature, reflects the possibilities of foreign travel opened up as a result of the considerable development of commercial aviation during the 1960s;
- the second, a direct reflection of telecommunications development, was the introduction of the automatic international telephone service. The need to interconnect and ensure perfect interworking between national telephone networks which had hitherto operated in total isolation called for a thorough knowledge of the network specifications of the foreign partners, what they shared in common and what was specific to each.

Travel and technical missions abroad were to become commonplace from the 1960s onwards. In parallel with such bodies as the CCITT, regional organisations were coming into being: e.g., in Europe, the extremely active European Conference of Postal and Telecommunications Administrations (CEPT), with intra-European meetings following one another at an ever increasing pace. Similarly, the meetings of the IEEE – which until then had been specifically North American – began opening up in the 1970s to a

[6] In those days, an engineer who wished to know what was going on outside the narrow arena to which he was more or less confined – and there were few so curious – simply had to rely on foreign technical journals which might find their way onto his desk.

broad audience of engineers from every continent. Its annual International Communications Convention (ICC) was to become a forum offering one of the best sources of mutual information on telephone developments in the major industrial countries.

2.5. Telecommunications development financing and the constraints to which it is subject under State administrations

2.5.1. Two opposite trends or concepts have always been manifest throughout the past century and a half of telecommunications history, namely:

– an entrepreneurial spirit,
– a spirit of administration.

The two are intermingled, sometimes divisive and sometimes complementary, and between them they have woven the structural fabric of the telecommunications networks.

The first of these trends is distinguished by the urge to innovate and, to that end, the enterprise does not hesitate to resort to outside financing on a large scale.

The second is dominated by considerations of prudent management and a concern for guaranteed economic viability: the administration saves its pennies and rejects all outside interference, preferring complete autarchy even at the expense of any possibility of expansion.

2.5.2. Finding the large amount of capital needed for a telephone agency is and has always been a major concern of management [1–3]. There are several strategies possible, each depending on the conditions specific to the country concerned and on the status (State administration or private operating agency) of the telephone operator.

In the case of private operating agencies, with the USA as the outstanding example, capital is raised on the money market. One essential condition for stimulating the flow of this capital is the confidence of the investors, and this confidence implies "an appropriate rate of return, i.e. an appropriate rate of benefit for the company" over the years.

In the case of State administrations, there is a whole range of situations, generally arising out of the legislation and administrative regulations peculiar to each country. Most often, and specially until the end of the 1970s, the rigidity of these constraints was a decisive factor for slowing down the development rate of a national telephone network managed by a State administration [7)].

When policy makers in some countries with State administrations decided in the 1970s to break down these constraints, especially the ones related to access to external funding and long-term foreign loans, a great deal of imagination and an even more vast fund of energy and determination were required from them to modify the maze of administrative regulations and negotiate the variegated combinations of external funding. Cutting the Gordian knot of the administrative and legislative bonds which hampered the access of telecommunications to the capital required for their development, presupposed decisive action to be sustained by consistent activity over many years.

(A typical example of such a radical change of policy in a country is offered by France. In 1976, an ambitious program of development to be supported by large resources of external financing was launched, with the result that the existing pool of only 7 million telephone subscribers was expanded to 20 million by 1982. A yearly production score of two million new telephone subscriber lines installed during the last years of this

[7)] An analysis by the Arthur D. Little (ADL) consultants of the financing needs of the leading industrialized countries, published in "Telephony" in 1972 [4], perfectly portrays the behaviour manifested at the time by European telecommunication administrations in the face of an insatiable and explosive demand. Its judgment is a harsh one: "All of ADL's recent research suggests that the growth of telecommunications is noticeably inhibited by government control and bureaucracy... This has been the pattern just about everywhere outside of North America: telecommunications carriers are government departments, integrated into the civil service with all the bureaucratic procedures, personnel policies and annual legislative budgetary procedures that entails."

period put French telecommunications in the position of the country's largest investor [5].)

3. Telephone operating agency structures in the 1980s

3.1. As described in section 2, the TOAs' structures had remained static and virtually immutable from time immemorial. They were regarded almost as sacred monuments that would endure forever. All that started to change at the end of the 1970s and, indeed, in many of the most important countries, the structures were shaken from top to bottom in the mid-1980s.

3.2. Compared to the scene offered by the TOAs in the first half of the 1960s, the change was radical. Erupting in the United States with the suddenness of a tornado, the high winds of "deregulation" have cut a deep swathe and are still gusting mightily. Their effects have crossed the oceans and had violent and far-reaching repercussions in Europe and Japan. In 1988 we have not heard the last of them and they will probably continue to rumble on until the dawn of the twenty-first century [8].

If we are to assign a characteristic turning point to those radical structural changes, we can certainly point to *1 January 1984* as marking the dismantling of the activities of the all-powerful AT&T in the United States (see Box A). It must be realised, however, that this point at which the pendulum started to swing was exclusively an American affair and simply reflected the coming to fruition of a compromise reached in August 1982 between Judge Harold Greene of the US Federal Judiciary and AT&T Chairman Charles L. Brown, a compromise which put an end to bitter legal and administrative strife which had lasted a dozen years.

The compromise in question marked the end of a gradual process of erosion [9] of the *de facto* [10] monopoly, virtually equivalent to a Royal privilege, enjoyed by AT&T in the United States. While it required AT&T to shed its 24 Bell Operating Companies (BOCs), it also allowed the company greater leeway by:

- freeing it from the strict confines of information *transmission* and enabling it to engage, at least potentially, in information *processing*;
- enabling it to extend its field of activities beyond the United States and its international telephone service.

More than enough (e.g. [7–11]) has been written about Judge Green's historic decision, about deregulation in the United States and its positive and negative effects. This is no place to expatiate on such matters which are still giving rise to interminable controversy, especially outside the United States and even more particularly when it is a question of deregulating international/intercontinental telecommunication services. However, see Box B in this latter connection.

3.3. Moreover, the AT&T's divestiture which came about in the United States is only one aspect – although certainly the most visible – of the gradual changes that have affected most TOAs in countries with developed telecommunication systems. While the impact of such changes has been more drastic in some countries than in others, nonetheless a general pattern emerges:

[8] "Listening to the advocates of various national policies and practice (for telecommunications), one senses parallels with theological disputes", (H.M. Boettinger in [6])

[9] Important stages in this process were FCC decisions related to the operation of long-distance telephone services and connection of terminal equipment for data services. The most important of these decisions were:
1968 Interconnect (Carterfone)
1969 Specialized carrier (MCI)
1973 Value-added network
1976 Value-added network (resale carriers)
1980 Computer inquiry II

[10] A *de jure* monopoly, too, enshrined in the Communications Act of 1934 and the "Consent Decree" of 1956, administered by the Department of Justice and the Federal Communications Commission (FCC).

Box A

The former AT & T and what became of it following its divestiture

1. Before 1 January 1984 when it was officially divested, AT & T had been the most heavily capitalized company in the world, far ahead of even the oil industry majors. Although financial analysts were fully familiar with that situation, many of the world's telecommunication experts simply contented themselves with the knowledge that AT & T was at the world level by far the largest of all telecommunication enterprises.

AT & T's power and private status, which gave it a public service monopoly over some 80% of United States telephone subscribers, was bound to give rise to widespread controversy in the country and, at the national level, the Federal Department of Justice was no longer able to remain aloof from it. In 1974 it brought an antitrust action against AT & T on the grounds that the company was trying to reduce and even eliminate competition in the telecommunication sector. Like everywhere else, justice in the United States is a slow business and the case in question remained in abeyance for eight years.

Other events occurred between 1974 and 1980. They stemmed from decisions by the Federal Communications Commission (FCC), which also related to the right to compete with AT & T. The best known of these were the Carterfone (right to connect non-AT & T terminal device) and MCI (right to establish an inter-State long-distance route) decisions which worked against AT & T and the case against it by the Department of Justice.

After lenghty legal discussion and many attempts to find a compromise rather than have a legal decision imposed, the Public Prosecutor's Office and AT & T managed in January 1982 to reach an agreement, the "Modified Final Judgment" (MFJ), whereby AT & T had to shed its 22 Bell Operating Companies (BOCs) operating at the regional level but kept the "Long Lines" providing its long-distance communications, as well as Western Electric – its manufacturer of telecommunication equipment – and Bell Laboratories. In exchange for shedding all the activities of its 22 BOCs, AT & T was granted the right to exercise – in parallel with its activities in fields subject to regulation – other activities in such non-regulated fields as data communications and computers. In the circumstances, the Department of Justice decided to drop its antitrust action. In August 1982 this agreement was legally approved by Judge Harold Greene and, in December of the same year, AT & T submitted its reorganisation plan to the Department of Justice.

2. The final agreement, signed in 1983, was implemented on 1 January 1984 and led to the creation of the new AT & T and seven regional telephone companies as the issue of the old AT & T.

2.1. Each of the seven new regional companies (the "RBOCs") reflects a geographical regrouping of a number of the 22 BOCs which used to provide the telephone service throughout the United States, excluding Alaska and Hawai. Their names are given below and their geographical distribution is illustrated in Fig. 1:

- Ameritech,
- Bell Atlantic
- Bellsouth,
- NYNEX,
- Pacific Telesis,
- Southwestern Bell,
- US West.

2.2. The new AT & T had five divisions. These included "AT & T Communications" which, in terms of earnings, was far more important than the Long Lines Department within the pre-1984 AT & T. In addition to Western Electric (now "AT & T Technologies") and Bell Laboratories which retained their old structure but are now divisions of the new AT & T, the remaining two divisions were:

- AT & T International, responsible for sales abroad and, more generally, for all activities outside the United States;
- AT & T Information Systems, responsible for selling "Customer Premise Equipment" and developing computer and "informatics" activities. This division (AT & T-IS) replaced "American Bell Inc.", which had only a short existence after it was set up in 1982 to look after the provision of enhanced services and the supply of new and sometimes extremely sophisticated subscriber terminal equipment.

Box A (followup)

2.3. Even more than the specialized telecommunication press, America's leading newspapers described in all their complicated details AT&T's new structures following its divestiture and the difficult problems which inevitably ensued. For instance, there was the problem – to name but one – of what the "operator" of the long-distance service should pay the local telephone companies (whether they were issued of the Bell System or an "independent "company) for access to the long-distance service.

Bibliography of Box A

K.R. Scovill (ed.), An Introduction to the Regulation of Telecommunications, Telephony Publishing Corporation, Chicago, 1985, 335pp.
Spectrum (IEEE), Dec. 1988, p. 27 (for Fig. 1).

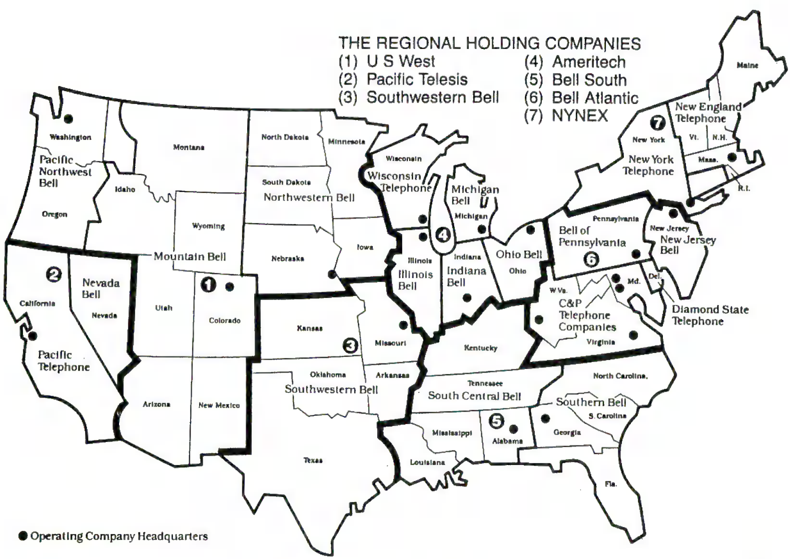

Fig. 1. The seven holding companies divested from AT&T, each serving one of the regions outlined in a bold line.

Box B

Insight into the controversy surrounding the deregulation of international telecommunication services

The problems posed by the current trend towards "deregulating" international telecommunication service operations are complicated by the fact that the very term itself presupposes the existence of a "regulating authority". International deregulation would therefore presumably require that an international authority existed for establishing the regulations to be applied, one which was moreover in a position to decide how they should be modified. Unfortunately, this is not the case at the time of writing (1988).

The ways in which the international telecommunication services are operated have hitherto simply reflected a *de facto* consensus as to practices which were for the most part defined in CCITT Recommendations. On the whole those practices were faithfully observed by the TOAs under mutual agreements (usually in the form of tacit arrangements) between the partners at the ends of the relations served.

For the past two years that *de facto* situation has been under attack. A perfectly accurate juridical interpretation of the terminology which qualifies the conclusions of CCITT studies as "Recommendations" has formed the basis of recent decisions, e.g. by the Court of Justice of the European Community, whereby the binding nature of those Recommendations is refused. As a result, the Recommendations have lost much of their former moral force as rules of good conduct and it is to be expected or feared that the breach in the consensus that has been obtained with them until now will lead to their being seen as no more than pious exhortations. Legally, therefore, we are faced with a fragile house of cards, one which hitherto has been generally approved but might now collapse if it is undermined by defection of the leading international telecommunication operators.

International deregulation may therefore eventually mean a complete lack of regulations. The effect of such a vacuum in the international legal order would be to leave the field open solely to such initiatives as may come about under bilateral agreements between countries. In particular, such a situation would face many countries with a dilemma, not to mention heavy cuts in revenue, if the practice of routing traffic to them via a third (transit) country would become widespread.

a) the TOAs now have greater freedom of action than in the 1960s and, in particular, they have access to financial markets;
b) their operating market has been opened up to some degree of competition;
c) TOAs have been given greater autonomy due to slackening of various State management controls, according to one or another of these processes:

- autonomy of management for the separate postal and telecommunication branches wherever a single official PTT Administration has been maintained;
- total separation of postal and telecommunication services, with the latter acquiring public corporation status and operating under ordinary commercial law;

- privatization of TOAs and the distribution of their capital as shares for public subscription.

3.4. One does not have to look far for the underlying causes of the profound changes that came about in the mid-1970s:
- considerable advances in technology leading to substantial reductions in telecommunication service costs;
- diversification of telecommunication services on offer to the public, again a product of technological advances;
- an exploding demand;
- and, consequently, the financial power of the TOAs combined with their growing need for investment capital in order to cope with that demand.

Albeit with much beating about the bush in some cases, all those reasons combined to break the mould of forms of management which were no longer suited to the times in the "New Industrial Revolution" of a "technotronic" society which began to appear in the 1980s.

3.5. A large spectrum of solutions for the "liberalization" of the TOA's structures have been adopted or are in view in various countries at the end of the 1980s. Here, we shall only focus on the two most important cases of radical reforms, those which occurred in the United Kingdom and in Japan.

3.6. The United Kingdom [1,12–14]

3.6.1. In comparison with other countries, it is unquestionably in the United Kingdom that the telecommunication situation has undergone the greatest transformation in the past two decades.

The structures of the Post Office remained unchanged during the post-war years and for the twenty that followed, i.e. they were completely under State control. The investment needed for developing and modernizing Britain's network was, much of the time, tied down drastically to allow for national budget restrictions imposed by economic circumstances. As a result, the authorities responsible for telecommunications within the Post Office were subject to a stop-and-go policy which was, of course, highly detrimental to proper service operations. As in many other countries at the time, the British governmental authorities regarded telecommunications as just another minor sector of the economy.

It was only in the mid-1960s that things started to show signs of moving; and move they did, very gradually at first but eventually in the direction of radical change.

The pressure of demand and the diversification of services as a result of technological advances contributed much to the changes, but not so much as did the political options taken by the central authorities. The Labour Government in power in the 1960s was to adopt a public corporation status, one it favoured as reconciling some autonomy of action with governmental piloting based on a small number of indicators for measuring the corporation's performances. Conversely, the Conservatives, in power since the late 1970s, have preferred to separate the Post Office's postal and telecommunication activities and end the monopoly over "new services".

The main stages in these developments are briefly outlined below.

3.6.2. In 1969 a major set of changes took place in the structures of the British Post Office and marked its divorce from civil service status. A Post Office Act established a Post Office Corporation and defined its statutory relationship with the State. The Post Office Corporation became responsible to Parliament through the Secretary of State for Industry. In the description by the 1969 Post Office Act of the terms of reference of the Post Office Corporation, its "exclusive privilege" (i.e. monopoly) for telecommunications was explicitly maintained.

3.6.3. Another major step was accomplished in 1979 by the separation of the postal and telecommunication activities into two separate State corporations.

According to the recommendations of a 1977 Post Office Review Committee ("the Prof. Carter

report") [15], a 1979 British Telecommunications Bill transferred the monopoly of telecommunication operations from the Post Office to a new public corporation known as "British Telecom" or "BT", allowing it a three year period in which to separate itself from the Post Office.

3.6.4. In July 1980, the House of Commons was told that the Thatcher Government planned to phase out BT's monopoly over telecommunications. A British Telecommunications Act of November 1981 embodied most of the recommendations in a Report ("the Prof. Beesley report" [16]) by a Committee commissioned by the Department of Trade and Industry, and put an end to BT's monopoly.

In February 1982 the Mercury consortium, a private company, was licensed for a 25 year period to provide, in competition with BT, basic switched services between a number of the country's largest cities. Later, it was allowed to enter into competition with BT for providing international services. Initially a consortium including two important financial partners (British Petroleum, Barclays Bank), Mercury became after 2 or 3 year's existence a 100% subsidiary of the old and famous Cable and Wireless Company.

3.6.5. In December 1984, after the adoption of a new Telecommunications Act, BT received the status of a "Public limited company" or Plc. A small governmental office, the OFTEL (OFfice of TELecommunications), became the regulatory body for UK telecommunications. The privatization of BT gave rise to a first public stock offering of 51% of its shares. The three billion shares involving almost 3.9 billion pounds (US 1984 dollars = 4.6 billion) were heavily oversubscribed. At the time it was the largest public stock offering the world had ever seen.

3.7. Japan

3.7.1. In 1988, after the recent reforms to telecommunication agency structures in the United Kingdom and Japan, one cannot fail to notice that the new structures introduced in each country are in all respects comparable. This is particularly true of the basic changes made, namely the abolition of the former monopoly over public service operations and the privatization of the agencies responsible for them.

While the upshot of these reforms has thus been more or less the same in the two countries, it is quite obvious that the situations from which they arose could hardly have been more different. Nor, indeed, could the course of events which led up to the new common structural model: whereas an innovating public corporation status had existed in Japan since the early 1950s and the decision to privatize and to scrap the monopoly situation was taken somewhat abruptly in 1984, matters in the United Kingdom came to a head only after a lengthy period of evolution. The British Post Office acquired its public corporation status in 1969 but it was not until 1979 that telecommunication and postal activities were separated with the creation of British Telecom; in Japan, on the other hand, the Nippon Telephone and Telegraph Corporation (NTT) had come into being as early as 1952 and was endowed with both these fundamental attributes of autonomy.

3.7.2. In the early 1980s before NTT was privatized, the corporation's position in Japan was regarded as extremely healthy and, contrary to foreign views of the situation in the United Kingdom, observers from many countries beheld its structures as exemplary for reasons which certainly include the following:

- the subscriber population;
- the ubiquity of the telephone, with countless red or yellow sets liberally made available to the public on the streets and in shops and popularized in a wealth of illustrated magazine articles on the merits of Japan;
- the country's extremely modern national network;
- an ingenious financing system based largely on down-payments from subscribers (and future subscribers) for securing the investment needed for network development.

3.7.3. In the case of the international service, the position of KDD, a private corporation instituted by special law in 1953 just one year after NTT and exercising an international monopoly, was no less brilliant. Even if international traffic accounted for only about 4% of total telecommunication spending in Japan owing to the combination of the country's geographical distance from other industrialized countries and the language barrier between Japanese and foreign partners, KDD's international traffic over the past few years has been expanding at the phenomenal rate of about 40% per annum.

3.7.4. Accordingly, given a situation which foreign observers rightly regarded as ideal for the Japan's development of domestic and international telecommunications, one might justifiably wonder what sparked the radical change in their structures in 1985, "an epoch-making year for Japan's telecommunications" [17].

Political decisions were no doubt the root cause, and Japan was certainly influenced by the example of the no less radical reforms in the United States and the United Kingdom, both of which had governments of similar political persuasions. Last but but not least, Japan had carefully worked out the decisions to be taken for dealing with the technological explosion paving the way to tremendous diversification of services and a vast potential for novel action. An excellent account of this reasoning is given in [14] by M. Koyama, the Japanese Vice-Minister of Posts and Telecommunications; (see also [18] for a description of the rationale for privatizing NTT).

Here follows a brief outline of the main stages which gave rise to the radical reforms of TOA's structures in Japan.

3.7.5. An Administrative Reform Ad Hoc Committee, called "Rincho" and "consisting of university professors and industrialists who were the largest sponsors of the Conservative party" [18], had been established in 1981 to research and consider fundamental matters concerning the reformation of administrative systems and management in Japan. In July 1982, it recommended *inter alia* that NTT should become a private company.

Under the inspiration of the Rincho group, and with Mr Nakasone as Prime Minister, three Bills concerning the status of Japanese telecommunications were passed in the National Diet on 24 December 1984. The Telecommunications Business Law to open up the liberalization of the telecommunication service industry was enforced on 1 April 1985. It introduced the principle of competition in the various services, i.e. telephone, leased circuits and data communications. This principle was applicable to domestic and international telecommunications and to trunk and local circuit services.

According to this Law, telecommunication businesses are classified into two types:

- Type I, providing services with their own telecommunication circuit facilities,
- Type II, not owning telecommunication circuit facilities but leasing them from Type I telecommunication carriers. A further subdivision is introduced within Type II between: "*General*" and "*Special*" Type II telecommunication businesses, depending on the size of the facilities and other factors such as the way of use.

The Ministry of Posts and Telecommunications (MPT) is the regulating body for telecommunications. It grants entry permission to companies to serve as Type I telecommunication carriers, registers companies wishing to operate as Special Type II carriers, and, for the operation of General Type II, asks only to receive notification of the opening of the service.

In mid-1986 five companies besides NTT had received the status of Type I carriers, and more than 250 enterprises had already been established to offer value-added network (VAN) and other General Type II services [19].

3.7.6. NTT, now registered since 1 April 1985 as a private enterprise with the status of Type I carrier, naturally maintains its position of prominence among all other companies in the Japanese telecommunication industry.

In the autumn of 1986 a first issue of its shares was offered on the public market for Y1.2 mil-

lion each, a breathtaking 133 times the company's earnings. The new NTT shareholders were, however, quite happy because the shares have risen substantially in value since their initial issue. Even if the share is the most expensive one on the Tokyo Stock Exchange, the second issue of shares (nearly 2 million) was also a success and was fully subscribed by November 1987 in spite of the Wall Street crash a few days earlier.

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CHAPTER XI-4

SOME ECONOMIC VIEWS CONCERNING SWITCHING WITHIN TELECOMMUNICATION AGENCIES

1. A macroeconomic overview of the financial importance of switching in telecommunications

1.1. The exercise of compilation of telecommunication statistics to obtain financial values of the telecommunication market at world level has entered into current practice during the past fifteen years (the first one in 1972 [1]). Such an operation can give only approximate values, with an uncertainty margin of, say, 10% or possibly 20%.

This margin is due first of all to the fact that, at least at the time of the early- and mid-1980s, telecommunications represented one of the rare sectors of the world economy experiencing a high development rate: a general average of 5% to 10% a year for national services, and 15% to 25% a year for the international service. Any estimate at a given time is thus only a snapshot of a situation and is already obsolete when carried out within a delay of one or two years, which is the case when the analyst has access to the worldwide data collected, for example, in the excellent "ITU Statistical Yearbook".

Another source of unreliability, as already mentioned in Chapter XI-1, is the absence of a standard and unfluctuating monetary unit to express the analyst's estimates [1].

1.2. With all these reservations, it is better to simply trace broad outlines of what telecommunications, and specifically switching, represent on a world scale. To this end, we shall refer to quasi-invariable ratios between the four basic (and classical) economic aggregates in telecommunications that are:

- the annual turnover, or global income, of "common carrier" telecommunication operators;
- the annual level of equipment investment placed by these enterprises;
- the share of switching equipment in their plant investment;
- the capital invested in telecommunication equipment (known as "plant value" in American usage).

1.3. The first of these four aggregates is the sole and unique one which gives very reliable values. It can be obtained by compilation of the financial data appearing in the "Yearbook of Common Carrier Telecommunication Statistics" published by the ITU.

Extremely accurate figures of income accruing from:

a) telecommunication services,

b) telephone operation,

are annually produced by the accounting departments of telecommunication agencies, are compiled nationally [2] and are submitted to the ITU by almost every country in the world. These

[1] "The choice of (a common) currency unit for the indicators of (a world wide) statistics has led to non-significant statistics.. " [2a]

[2] a national compilation which is necessary where several telecommunication/telephone operating agencies exist in a country, e.g. in the United States where this compilation is a laborious and lengthy process.

figures are expressed in national monetary units, but an official US dollar conversion rate is also given in the ITU Yearbook. An incomparable work tool for any serious macroeconomic study of telecommunications at the worldwide level is thus provided by the ITU Yearbook. Although it is often too little known, many of its data find their way into other world-wide statistical publications which, having a more generous distribution, reach a wider readership.

If highly reliable, the value of the first above aggregate, provided by compilation of the ITU Yearbook data, is unfortunately available only for periods which precede by almost two years the dates on which it can be obtained.

1.4. The order of magnitude of the three other aggregates mentioned in 1.2 can be deduced from the value of the first aggregate by applying standard ratios which, in the main and averaged both in time (over the years) and in space (from country to country), are quasi-permanent.

The three simple and easily memorizable standard ratios are as follows:

- about 25% of telecommunication agency revenues is employed in equipment investment, for either replacement (with money coming from "depreciation/amortization" funding) or expansion of equipment;
- about 30% of equipment investment relates to switching equipment;
- the value of the equipment or, as the Americans would call it, the "plant" of a telecommunication agency is roughly two and half times that of its annual revenues (a ratio known as "the Huntley's Law" [3–5]).

Obviously, these standard ratios have no normative value but simply represent averages for a number of years and with all countries taken together.

1.5. What interests us here is, of course, the third of the above mentioned aggregates, giving us the order of magnitude of the market offered to switching equipment manufacturers by the public telephone agencies.

At the time of writing (1987), the following overall estimates, – very rough estimates – may be advanced:

- US$ 250 billion receipts/revenues [3] for all public telephone agencies;
- US$ 60–65 billion for their equipment investments;
- US$ 18–20 billion in their switching equipment;
- and very roughly US$ 650 billions for capital invested in the world's telephone networks.

Note: Because of the monetary upheavals in cross-exchange rates that have marked it, 1987 is perhaps not the most fortunate year for publishing world macroeconomic estimates. However, it does have the advantage of lending a certain artistic haziness to the presentation of the above values two years before the annual turnover in 1987 of common carrier telecommunication operators (first of our basic aggregates) will become known.

1.6. Lastly, in determining the order of magnitude of the turnover of switching manufacturers, full allowance should be made for the large share accounted for by products other than those intended for public telecommunications networks. If this share [4] is estimated at roughly 20–25% of their turnover, the switching market in 1987 for both public networks and private installations may be estimated at some US$ (1987 value) 23–26 billion – a sizable figure which is generally known to only a few experts and analysts.

There are, of course, other methods (e.g., methods based on surveys of the switching equipment manufacturers' sales) to reach figures which the author believes to be consistent with and perhaps not better than the ones quoted above.

[3] The "OMSYC" Communication Systems Statistics [2b] gives a higly precise value of US $264.521 billion for 1987, value obtained by compilation of data published in the ITU Statistical Yearbook.

[4] Without forgetting equipment for military and related applications, a subject which generally appears only discretely in "proprietary reports" not accessible to the public.

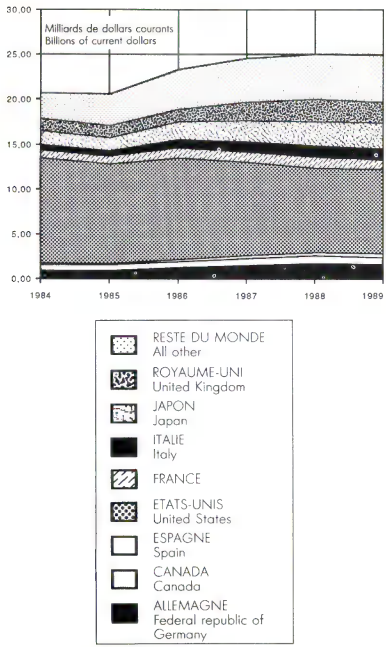

Fig. 1. The world switching market (values in current US$ billion), from [2c].

As an example, the statistics of [2c], published in 1989 and discovered just before closing the manuscript of this book, give a more precise value for the 1987 world switching market (a value quoted with – perhaps some illusory – four significant digits): 24,64 US$ billion. The same publication offers also a most valuable Graph, reproduced here as Fig. 1, showing the distribution of the world switching market, in both geographical distribution and time/years. As can be seen on it, the relative shares of this market demonstrate the absolute predominance of the American market, with more than 50% of the world market in the United States.

1.7. Statistical figures may be useful but beyond a certain size, they have the drawback of being difficult for the layperson to grasp. We sometimes need to be more practical.

To be more specific, let us for comparison take an example which might be striking since it refers to one of the most modern sector of communications, i.e. the commercial airlines, a sector bearing some analogy to telecommunications (e.g., comparable rates of traffic growth and technical development).

The amounts spent annually:

- by airlines for purchase of commercial (civil) aircrafts, according to data published by the International Air Transport Association (IATA),
- by telecommunication companies on switching equipment alone,

are of the same order of magnitude [5]. This comparison is important and merits to be known.

2. Relations between telecommunication agencies and the switching equipment industries

2.1. The companies making up the telecommunication equipment industries are subject to a very specific market situation. This applies particularly to the manufacture of switching equipment.

In most industrialized countries, the specific nature of these markets is due to the existence of a monopolistic telecommunication operating agency. In most of these countries, a State administration (or a State-owned agency) determines the type of product and the scale of production, establishes the standards on which the specifications are to be based and selects the systems to be brought into operation. Very often it also exerts a dominant influence on research and on system development. In the case of State administration (or State-owned agency), political

[5] But the media are devoting 10–20 times more to news coverage concerning civil aviation than to dealing with telecommunications, and particularly its "poor relation", switching.

decisions fixed by Parliament and/or governmental authorities, particularly those concerning procurement financing, are one of the determinant factors of the pace of development of equipment suppliers. Moreover, the decisions taken by a national administration often call for cooperation agreements between competing firms within the country and impose radical changes in the strategy specific to each company.

2.2. In many industrialized countries, the national telecommunication agency also acts as the "guardian" of the national equipment suppliers. By fixing specifications and standards for the national network equipment, it imposes specific constraints, thus preventing or at least restricting equipment installations of systems developed by manufacturers of a foreign country.

Furthermore, and specially when this agency is a State administration, it often exercises activities connected with its country's industrial policy, activities going far beyond what would be its normal responsability – which, indeed, is to run the national telecommunication service. These activities, sometimes vigorously pursued, consist in promoting the exports of its national equipment industries. Several administrations have thus chosen to take an active, though often unofficial, part in setting up in their countries "subsidiary companies" or offices designed to perform tasks of international technical expertise and have consistently supported them in carrying out these functions.

2.3. While these very general comments apply to the whole of relations between telecommunications operating agencies and their manufacturing suppliers of equipment, the switching equipment sector is certainly the one for which they apply the most specifically.

3. Advantages and drawbacks of the generalized use of one unique switching system only

3.1. Lack of system uniformity in a country increases costs:

- firstly, there is the cost of manufacturing different equipment, which precludes the economy of scale obtained from a single type;
- secondly, there are the management and running costs, a very important factor becoming apparent only at a later stage. To install, maintain, document and train personnel for a whole range of different types of equipment costs more than for only one or two types of standard equipment.

3.2. On the other hand, rigid uniformity of equipment types also gives rise to problems:

- first of all, inertia. When a country has only one system, any change in the type of system will involve a radical decision, inevitably preceded by very lengthy studies. Any change from a single standard system encounters bureaucratic and, in countries with a State administration, political constraints. These constraints will have the effect at best of delaying a decision and at worst inhibiting any development;
- the adoption of one single system for regions with widely differing population density, urbanization characteristics, etc., may entail increased costs due to the unsuitability of the equipment to its environment;
- finally, equipment uniformity rules out the possibility of objective comparison: it becomes very difficult to decide whether the standard system in force is in fact the best or even whether it is still viable, since no objective or financial bases are available for comparison.

3.3. For all these reasons, in many countries, whether large industrialized countries or developing countries, a general procurement policy of telecommunication agencies is to install switching equipment of two (and sometimes three) different systems, normally from two (or three) different manufacturers, and at least during a long period corresponding to a given generation of switching systems. It is a market situation known to economists as a "duopoly" situation, as opposed to the one of "monopoly" (or, more precisely, as "duopsony" as opposed to "monopsony").

Table 1
The 1985 market for public exchange orders in European countries

Country	Switching manufacturing firm	% share of the national market
Austria	Siemens	
	ITT (under Siemens license)	50
	Other Austrian firms (under Northern Telecom license)	50
Belgium	ITT (BTM,Antwerp)	80
	GTE	20
Denmark	Ericsson (AXE)	80
	ITT	20
Finland	Nokia	50
	Ericsson	35
	Siemens	15
	CGCT	16
Germany	Siemens (EWSD)	60
	ITT (SEL) (System 12)	40
Ireland	CIT-Alcatel (E10)	40
	Ericsson (AXE)	40
Italy	Italtel (+GTE)	60
	Others (ITT, Ericsson)	40
Netherlands	APT (Philips + AT&T)	75
	Others (ITT, Ericsson)	25
Norway	ITT (STK) (System 12)	100
Spain	ITT (System 12)	70
	Ericsson (AXE)	30
Sweden	Teli (Swedish Administration) (AXE)	75
	Ericsson (AXE)	25
United Kingdom	Plessey	44
	GEC	29

As an example, we reproduce as Table 1, the data published by an OECD publication [6] concerning the approximate shares of the 1985 market distribution of orders for public exchanges in European countries.

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[1] Chapuis, R., Common carrier telecommunications in the World Economy, Telecommunications Journal, Oct. 1972, pp. 601–620.

[2] OMSYC, Communication Systems Statistics, 1989 edition of Telecommunications Statistics, Paris: a) p. 6 ; b) p. 12 ; c) p. 14.

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[4] Bower, L.L., Telecommunications market demand and investment requirements, Telecommunication Journal, Vol. 39, March 1972, pp. 177–181.

[5] Chapuis, R., Economic Analysis of financial structures of a Telecommunication Operating Agency, ITU (Telecom Economic Division) Paper, March 1985, 75 pp.

[6] OECD, Labarrère, C., L'Europe des télécommunications, Masson, Paris, 1985.

CHAPTER XI-5

THE SWITCHGEAR MANUFACTURING INDUSTRY. 1965–1987: A THOROUGH SHAKE-UP IN ITS STRUCTURES

1. Perfect stability of structures until 1975

1.1. From the 1920s, when the automatic telephone industry first found its feet, the structures of the switching equipment manufacturers were virtually static and remained so until about the mid-1970s.

The 1940s, with the Second World War and its immediate aftermath in bomb-torn Europe and Japan, may thus be viewed by historians as a mere hiccup in the life of the thirty or so companies operating in this branch of industry, although their activities admittedly underwent substantial changes when the bulk of their production was geared to the war effort. In their factories, electronics then emerged for constructing radio and even radar equipment. In spite of these incipient technological changes, by 1950 the industrial pattern was the same as it had been before the war; indeed, as it had congealed once and for all in the 1920s.

1.2. As it is well known in the telecommunication world, the switching industry's market is based primarily in some ten countries and subsidiarily in another dozen, most of them in Europe and all of them highly industrialized.

Until the early 1980s, the market in each of those countries was strictly isolated. Only companies with a national base could expect contracts in the public switching sector [1] of their country because:

a) the Administrations or national operating agencies holding telephone monopolies in Europe and Japan had traditional administrative rules which precluded outside competition;

b) in North-America, each of the three major manufacturing companies belonged to a telephone operating corporation: Western Electric to AT&T, General Telephone had its own factories, and Northern Electric, later to become Northern, was an affiliate of Bell Canada.

1.3. Switching manufacturers thus had only a fairly lean export market in which to fish for competitive contracts, i.e. in those countries which, although not at all industrialized, were in some cases fast becoming so, and in Third World countries. Taken together, these accounted for only about 5–10% of the world market, although this percentage was considered likely to rise in the more or less distant future.

Naturally, therefore, the competing manufacturers started in the 1950s to view that export market as a hunting ground in which to engage in fierce and bitter rivalry, although even the gentry represented by the leading names in switching could field only a few crack shots. These were led by LM Ericsson, Siemens and the Japanese [2], followed later by others such as GTE, CIT-Alcatel and Northern.

Indeed, a certain amount of courage was needed because the quest for overseas outlets

[1] In many countries, even the private switching (PABX, keysets...) market was subject to the same restrictions.

[2] The "Japanese" = N.E.C., Fujitsu, Hitachi.

consisted not only of nice surprises. In addition, setting up in a foreign market called, – and always calls –, for heavy investment. Moreover, there had to be strong motivation to go seeking industrial outlets abroad rather than remain content with, as it were, a national market derived from a privileged position held over decades of industrial practice; not that all manufacturers had been so privileged and, indeed, LM Ericsson was just such a case.

1.4. This situation in which markets were circumscribed and industrial structures set merely reflected, as both a mirror-image and a phenomenon of dependency, the structures that prevailed prior to the mid-1970s among the State Administrations or operating agencies which, in every industrial country of the world, held either a monopoly or a quasi-monopoly over the telephone. As we saw in Chapter XI-3, their structures were as unchanging as they were monolithic.

In those days, little interest by the public was taken in telecommunications, let alone in the equipment manufacturers who remained firmly in the background. The Stock Exchanges took little notice of their activities, even of those whose shares were specifically quoted (and only few of them were in such a position.):

- in the United States, Western Electric was only the manufacturing arm of the AT&T. The AT&T shares were gilt-edged securities, more like bonds with a fixed return, and scarcely fluctuated for any reason to do with the performance of the company and its Western Electric department;
- in Europe, activities relating to the production of telecommunication equipment were in most cases greatly overshadowed by the other activities of the large companies quoted on Stock Exchanges.

2. Radical Changes in 1975–1980

2.1. Everything started changing in the mid-1970s and the change was twofold:

- first, it was a technological change brought about by both the advent of microelectronics and SPC switching systems, and the increasingly diversified – and therefore costly – programming they required;
- secondly, it was a structural change which hinged on the first and marked the break-up of the rigid archaic structures which had formerly prevented the diversification of telecommunication services.

2.2. Technological historians may well point to the mid-1970s as marking the onset of what some term the "new industrial revolution". The explosive development of integrated circuit technology led to a dramatic reduction in the cost of the functions carried out by such components. In telecommunications it gave rise to the digitization of techniques and in turn to its following applications: data transmission, telephone transmission (the PCM systems), telephone signaling and, finally, telephone switching.

2.3. Microelectronics and integrated circuits are affecting countless fields other than telecommunications.

This is particularly true of the computer industry. Its products for information processing are ever more closely imbricated with those of the telecommunications industry, involved in information transmission. Both industries apply about the same techniques. Sometimes, on some border fields, they are in competition but, more often, in so far as the needs of their users are concerned, their equipment has to be directly connected and associated. Hence the need for an increasingly sophisticated diversification of their equipment to meet the wishes of the business world, i.e. those who are the most important customers for telecommunication services.

Thus the sudden or gradual wave of deregulation which has swept over the telecommunication agencies of so many countries in the 1980s comes as no great surprise; nor does its concomitant potential for opening up new markets to the manufacturers of telecommunication equipment.

2.4. Another phenomenon which was often dimly perceived in the 1970s [3] was the fact that increasingly efficient integrated circuits (LSI, followed by VLSI) had a considerable impact on the structure of switching equipment costs, in which software now counts for more than the lion's share [4]. As the services provided had to be more diversified, the size of the software steadily increased and is now often measured in several millions of lines of instructions. As a result, the cost of developing a type of switching system has sky-rocketed and can be amortized only if the system is mass-produced on a very large scale. This explains not only the determination of manufacturers to win ever larger slices of the market for their switching equipment, but also the current wave of mergers now unfurling within the industry itself.

[3] See, for instance, in the footnote of p. 407 of Chapter IX-6, the totally erroneous appraisal in 1978 of the magnitude of the programming work-load for the development of an ambitious SPC digital switching system.

[4] See, on this respect, the statement of the "Commission of the European Communities" (Brussels, EEC) in its "Green Paper on Telecommunications (30 June 1987)":

"For public switching systems, the cost structures have been completely reversed. In 1970, software, the major component of R&D costs, accounted for 20% of total development costs... By 1990, this ratio will be reversed: 80% for software development and 20% for hardware. Currently, the software to operate a public switching system comprises some one million programmed instructions. For the early 1990s, with the growing complexity of switches, it is estimated that this figure will have risen to three millions."

...

"A new public digital switching system will have to secure 8% of the world market to obtain sound economic viability."

...

"The cost of developing a digital telephone exchange system, including the development of the software, is over US$ one billion..."

3. Comparative figures for the switching industry in the 1960s and the 1980s

3.1. To get a sharper picture of the profound upheaval that has been (and, in the late-1980s, still is) taking place in the structures of the switching industry, let us now take a quick look at the main partners during two periods;

a) the 1960–1965 period;

b) the present, as this Chapter is being drafted (1987).

3.2. The first thing our scanning exercise reveals is that:

- for the first period, there is an almost total lack of literature valid at the world level on the subject;
- conversely, since 1975, there has been a wealth of documentation although not all of it is ideally consistent. Most of the publications available are based on statistics and analyses made by specialized consultancy firms like Arthur D. Little, Northern Business Information, D. Dittberner Company, etc. Summarized, their results are briefly covered up in such journals as "Telephony" [5].

Essentially American by origin, most of these statistical surveys are issued with figures expressed in monetary units which are in US dollars. In the case of world estimates, fluctuations in monetary exchange rates used to convert, say, West German DM figures or Japanese Yen figures are bound to cause some scepticism about the accuracy of these financial surveys, specially when read after some years. Similarly, in each retrospective analysis, values expressed in dollars must be readjusted to the "constant price" values prevailing for the year to which the analysis relates. Readers of many large-circulation reviews should therefore be warned about the small tables which illustrate and adorn them: the

[5] Another source is offered by the far more specialized, almost confidential, financial reports sent out to large investors and to banks which handle their customers' investments on the Stock Exchange. However, the bulk of these, although extremely detailed and updated at least annually, scarcely offer an overall picture since each report reflects only one company's activities, with many of these activities not related to telecommunications and even less to switching activities.

monetary values given should be interpreted with considerable circumspection, particularly if they reflect too many wholly illusory decimal points [6].

The job of the consultancy analyst is moreover a difficult one. Picking out the values of equipment data peculiar to a given sector of activity of a company is by no means an easy matter. To many manufacturing companies, the production of telecommunication equipment accounts for only a part of their turnover. In addition, new distinctions for our purposes must be drawn between the different telecommunication sectors: – transmission, – switching, – and terminal and peripheral equipment. Allowance must be made for the often blurred lines between these sectors and, indeed, for the differing lines drawn by some companies. A further but simpler distinction to be drawn in connection with switching lies between equipment for the public network and that for private telephony (PABX, Keysets, etc.). A final hurdle in making a consistent analysis concerns the manner of determining the value of equipment which, once it leaves the factory, has also to be installed – often at distant sites – and eventually inspected. Hence the present method, adopted initially by the A. D. Little consultant firm (E.A.Grabhorn and A.B. Kamman), which defines the equipment market in terms of "shipments" as priced at the factory, i.e. excluding insurance, freight and on-site installation.

3.3. For an overall picture we must therefore content ourselves with two very general Tables offering a fairly rough classification of most of the industrial switching companies at the top of the chart [7] and presenting comparative figures for the two periods mentioned in this Chapter, i.e. 1960/1965 and 1987 (or 1986–1988):

– Table A concerns the relative part (in per cent) of telecommunications activities in the

[6] A quotation of an article in "Telephony" by Dan S. Fargo reviewing in 1981 "Telecommunication spending in the world" is typical:

"In our view, the inflation factor has introduced so much variability into the spending statistics that one thinks of turning to units of telecom equipment themselves for absolute measurements... 'It is a puzzlement' as the King of Siam was once heard to say. Thus the reader gets some idea of the labyrinth one faces in trying to completely understand the figures."

[7] Fourteen key suppliers for the world's public switching market, according to a 1985 classification by Northern Business Information.

Table A
The relative share of public telecommunication activities among the largest multinational groups engaged in switching equipment manufacture

Firm or Group	Country (site of the Headquarters)	Telecommunication activities in %	
		in 1960/1965	in 1987
Western Electric (AT & T)	United States	100%	98%
Northern Electric Telecom	Canada	100%	90%
LM Ericsson	Sweden	85%	80%
GTE (General Telephone and Electronics)	United States	80%	20%
Alcatel NV	Netherlands (and France)	–	90%
Plessey	United Kingdom	–	40%
NEC	Japan	65%	40%
Siemens	West Germany	40%	35%
CGE (CIT-Alcatel)	France	25%	(see Alcatel)
Philips	Netherlands	20%	5%
ITT	United States (Europe, etc.)	20%	2%
Fujitsu	Japan	5%	20%
Hitachi	Japan	5%	5%

Sources: Tables from Volume I (p. 259) and from "En direct France Telecom"

largest international groups of the electrical industry (Note: only those concerned with public switching activities);

– Table B offers *a fairly rough classification of the industrial switching companies at the top of the chart*

Such classifications appear fairly regularly in the countless publications aimed at telecommunication industry management. They reflect the outcome of exhaustive research carried out by the consultancy firms which engage in detailed analyses of the equipment markets and financial situations of telecommunication companies. It is to them that journalists refer first and foremost before writing articles in journals of some standing intended for an audience unfamiliar with telecommunications.

Caveat:

3.3.1. The classification of multinational switching groups in Table B should be interpreted with great circumspection. It constitutes a simple picture – a reflection – of relative positions that are fairly well understood among engineers in the business but should be regarded here as being solely of indicative or purely symbolic value.

There are many reasons for the degree of uncertainty, or rather the percentage bracket, concerning the evaluations given in the Table:

1) the chief reason is that there are two very different ways of establishing the classification in Table B:

a) the first is based on financial data relating to the turnover a given group spends on producing switching equipment. Allowance must therefore be made for all the exchange rate fluctuations which, over the years, affect values expressed in national currency units when they have to be converted into a common monetary unit (United States dollar).

b) the second is based on objective data relating to the number of "subscriber lines" produced (including those evaluated in

Table B

Approximate shares of international telecommunication firms in the *worldwide public switching market* in the two periods 1960–1965 and 1986–1988

Estimates given in the form of an approximate "bracket" of percentage figures.

A = % share in the world market for the period 1960–1965

B = % share in the world market for the period 1986–1988

	A	B
Western Electric (AT&T) (1960–1965)	26–28%	
AT&T Technologies (1986–1987)		21–24%
ITT (USA, Europe)	12%	?
(ex CIT-CGE) (France)	1%	
Alcatel NV (1986–1988)		12–14%
Siemens (West Germany)	10%	9–10%
LM Ericsson (Sweden)	5%	9–10%
Northern Electric (1960–1965) (Canada)	2%	
Northern Telecom (1986–1988) (Canada)		10–11%
GTE (General Telephone and Electronics) (USA)	6–7%	2–3%
NEC (Japan)	3%	5–6%
Fujitsu (Japan)	2%	3–5%
GEC (U.K.) (each)	2.5%	Total for the three: 5–6%
Plessey (U.K.) (each)	2.5%	
Italtel (from 1987) (each)	2%	
Others: e.g. in 1986–1988: Hitachi, Nokia, Soviet systems, South Korean systems, Brazilian Tropico, Indian systems, etc.	25–30%	15–25% ?

Sources: Various publications, e.g. Arthur D. Little data in "Telephony", "Business Week", "Inteltrade", etc., Franco (G.L.): World Communications, 1987, Uxbridge (U.K.), etc.

"line equivalents", meaning equipment intended not for simple subscriber lines but for junctions or long-distance circuits switched at transit or tandem centres).

Both types of data should, at least in theory, match fairly accurately provided the cost per "line" unit is more or less the same depending on the manufacturer and the location of his market. In fact that situation does sometimes occur, although only sometimes, in the case of calls for tender giving rise to keen competition for a new national market. As a rule, however, such situations seldom arise because most of the markets are "captive markets" which do account for the bulk of the business of the groups mentioned in Table B. "High volume production keeps prices down" and, from country to country, there are very considerable price differences per "line" unit. For instance, according to an OECD estimate of price levels in 1982, "European prices of switching equipment were 60 to 100% higher than in the USA".

2) Another reason lies in the difficulty of interpreting the extent to which a switching system produced simply under licence or as a minority joint-venture is attributable to a given multinational group.

3.3.2. Lastly, readers of the fine classifications of multinational switching groups appearing in so many publications, particularly those with an advertizing slant, should be aware of the fact that some of them confine themselves solely to production statistics of lines installed (or even, "and in order") for *digital* exchanges. Hence the fairly considerable discrepancies between this type of classification and those relating to switching activities as a whole.

4. 1960s: The reign of electromechanical switching. A wide diversity of systems

4.1. To assess the state of the art in public telephony switching in the early 1960s, we shall refer to two excellent texts by E.M. Deloraine: a lecture delivered in 1964 to the XIIth Convegno Internazionale delle Comunicazioni at Genoa (Italy) [1], and an article in a 1965 issue of "Electrical Communication" [2].

Of these two texts, the 1965 article is the one which gives the more detailed description of the various switching systems then in service, even if its title ("Telecommunications in Western Europe") does somewhat narrow our field of exploration as to the world-wide state of public switching. However, to get an idea of the diversity of switching systems at the time and appreciate the relevance of the partial sample offered by Deloraine in his study and confined to Europe, suffice it to note the following circumstances to which the author referred in his 1964 lecture at Genoa:

- the situation in Western Europe differed sharply from that in North America where an extremely limited range of systems was being mass-produced: indeed, the range was confined to AT&T/Western Electric's crossbar systems and the Strowger systems of the step-by-step class produced by both GTE/Automatic Electric and Western Electric;
- Japan's switching industry was still in its infancy;
- in the other regions of the world there was practically no industry whose production was not geared to systems of foreign design.

Reviewing the various switching systems used in Europe, more specifically in each country and discounting the short-lived ones, Deloraine classifies those manufactured in 20 families with each family divided into several systems. His list of such systems then being produced in Europe alone totals no less than thirty-four.

Of these 34, ten were of the crossbar type: essentially those of LM Ericsson and, as a newcomer, the ITT Pentaconta. However, by far the majority of the systems in service and in production were of the step-by-step class, with "direct

switching", i.e. with absence of registers (Strowger type and the German HWD and EMD types) [8].

4.2. This extraordinary diversity of systems in use in the 1960s is a characteristic feature of the period. At the time there was room for different systems since they could almost work independently as they have done during the past decades. Interworking between systems was reduced to a minimum of specification clauses, which moreover were completely determined on a national basis. When in the 1950s the CCIF/CCITT had to design an international signaling system and define signals allowing a perfect interworking of the systems in service, it was not an easy task that they faced!

5. Mid-1980s: The reign of digital SPC switching

5.1 The diversity of switching systems and technologies, so characteristic of the 1960s, gave way in the mid-1980s to:

- a considerable reduction in the number of systems on the world market;
- a general consensus among the switching industry as to the best design of switching exchanges regardless of their size or place in the public network. This consensus also applied to private exchanges, particularly PBXs.

The heyday of digital SPC switching had arrived and from now on all new systems had to have stored-program control and digital switching networks. There was also a consensus as to the type of exchange architecture: it had to be modular as regards both hardware and software and decentralized in that microprocessors were used throughout.

Note: One is tempted in the latter half of the 1980s to believe that this consensus will endure for quite a long period of time, although the rapid developments in switching over the past ten years counsel against such long-term forecasting. However, fairly clear trends are emerging which point to the gradual adaptation of the now firmly established switching systems to new and far more decentralized – not to say fragmented – network structures, as well to the incorporation of new subscriber facilities, including first and foremost those of an ISDN. The huge sums invested in switching system design alone provide a convincing explanation for these trends.

5.2. The shift in technological opinion towards digital switching can be pinpointed fairly accurately as having occurred in 1980 or, to be even more precise, at the ISS meeting which took place in Paris in May 1979: for it was there that the development of digital systems destined to play a major role in a number of the largest national networks was officially announced.

Obviously, there was to be some time-lag between the development of such systems and the large-scale introduction of exchanges using their technology. Thus the promises of 1980 came to fruition only in the mid-1980s, when in many countries a large majority of new or replacement exchanges were installed with digital systems, while in some other countries orders were placed exclusively on digital systems.

5.3. The twenty-odd years between the periods we are considering, namely the 1960s and mid-1980, may be regarded by an observer taking a world view as an active period of transition. While space-division SPC systems spread rapidly in the major United States cities during the early 1970s, an example followed fairly promptly in both Canada and Japan, events elsewhere were to mature more slowly.

Indeed, the process took about 10 years to get off the ground in Europe because such systems were considered too expensive and ill suited to the construction of medium- or small-capacity exchanges of the sort most common in Europe's national networks.

There was of course considerable discussion of SPC systems – then mainly space-division systems – and the debates at ISS conferences, let alone the content of technical journals, were completely monopolized by descriptions of such systems being researched and analyses of the few systems already in operation. However, for all the talk, two world-wide surveys of SPC system

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[8] see the description of these systems in Volume I.

implementation – the first [3] published in 1976 and the second [4] in 1979 – show the relative novelty of introduction of exchanges of this type until about 1980. As quoted from [4]:

"The penetration of SPC systems, that is to say, the ratio:

$$\frac{\textit{number of SPC lines}}{\textit{all automatic lines}}$$

is still low on 1978. With the exception of the United States, where penetration is about 20%, the rate at world level is infinitesimal (3.2% in Japan and much less in other countries)... (However) 1979 forecasts in the United States provide for an SPC system penetration rate of 60% by 1985 and the programmes of many other countries are no less ambitious. Certain small countries or countries with rapidly expanding telephone networks are already planning the complete restructuring of their network on the basis of SPC systems for all or nearly all their exchanges."

6. Late 1970s–1984: Managers taken concern of the changing structure of switching system costs

6.1. Two major landmarks

6.1.1. The *early 1970s* saw SPC switching take off and cease being the exclusive preserve of AT&T and Western Electric, its industrial arm. SPC principles underlay all new systems developed in Europe and Japan, as well as in Canada, albeit with widely varying end-products.

6.1.2. The *late 1970s* witnessed the emergence of digital switching systems. The tide had turned and this time it was the European countries (France with CIT-Alcatel, Sweden with LM Ericsson) which provided the poles of innovation despite their late arrival on the SPC scene.

6.2. Changing structure of switching system costs

6.2.1. Stored programme control and, with the advent of digital switching, the disappearance of all electromechanical components from exchange design brought radical changes in the industrial processes of switching equipment manufacture.

6.2.2. There was a steady decline in the hardware element of such equipment. This was accompanied by a parallel reduction of labour [9] which inevitably faced management with problems, particularly at the political level in some countries.

6.2.3. Conversely, the number of development workers employed rose considerably, reflecting the soaring share of software expenses in production costs of SPC switching equipment. The advent of digital switching accentuated that trend; for exemple, one of the chief advantages of the ISDN concept in the offing lays in the diversification of services and applications it affords, one which inescapably entails more and more software development.

Programming necessarily implies departments specialized in software development and support. In the switching industry, these are becoming increasingly important:
- firstly, as regards manpower [10],
- secondly, as regards qualifications. The skills needed are proving ever more demanding and often have to be employed in such fields, unknown ten years ago, as computer-assisted design (CAD).

[9] Two typical examples:
– in the United States, Western Electric reduced its number of employees by 27% (from 207,000 to 151,000) between 1974 and 1977 [5];
– in France, Thomson Telephone's staff fell from 42,000 to 29,000 over the period 1977–1982, with cuts of 15,000 in the labour force, but the company managed to maintain its output of exchange lines [6].

[10] While *programmers* often represent *a majority component* in this respect, many other categories of engineer and technician are also required for switching system development.

6.2.4. The switching system development costs are now often estimated at ten or twenty times what they were in the late 1960s when electromechanical – particularly crossbar – switching was still in its heyday.

6.3. 1975–1984: Awareness of the new situation and the need for larger markets

6.3.1. Switching industry management began in the mid-1970s to take stock not only of the obvious and unsettling fact that their development outlay was increasing very rapidly, but also of the implications of that increase.

Research and development of a switching system is to be considered as representing an initial outlay, i.e. an (intellectual) investment. *The once labour-intensive switching industry has consequently become a capital-intensive industry.* If it was to afford a return, the amount invested in a given system necessarily implied critical mass-production thresholds, thus making ever broader markets a *sine qua non* of the system's success. As a President of Northern Telecom asserted as early as 1977, "You have to sell the world market to support the R & D".

6.3.2. In official statements at large international gatherings of this period 1975–1984, noble words on the value of greater cooperation between industrial switching groups unfailingly reflected this realization of the situation on the part of management (see, e.g., a lecture "Choosing allies in the battle for world markets" by Maria Bellisario in a 1984 "Financial Times" International Conference in London [7]). The OECD also made repeated exhortations along the same lines when introducing a detailed report on the fate of the telecommunication industry [8].

However, fine words and good resolutions were not enough and the stubborn facts still remained: in each major industrialized country, the switching market was still strictly reserved to local manufacturers and carefully preserved against any intrusion from outsiders. The technical specifications peculiar to each country were tantamount to battlements affording solid retrenchment.

6.3.3. Nibbling away parts of another country's market and taking advantage of cross-winds and counter-currents to introduce a foreign-developed system on the strength of its product quality, or setting up from scratch locally-based manufacturing plant of this system, are strategies surrounded with well-known difficulties. This is particularly true when setting up in industrialized countries because, while in the long term they may offer potentially large markets, they are unfortunately the ones in which one is likely to encounter local manufacturers who over the decades have secured an absolutely dominant position.

Some manufacturers tried this in the United States, looking to potential orders from the "independent telephone companies". With the exception of Northern Electric from neighbouring Canada, which successfully turned its North Americanness to account in cutting itself a large slice of the United States switching market, the results of such action in the United States generally left a bitter taste in the mouths of the initiators. In commercial if not academic jargon, some European manufacturers even lost their shirts there.

The strategy of the switching industry's leaders could therefore not elude the severe constraints of the law of concentration which at the world level governs all highly capital-intensive industries, of which the most familiar examples to the man in the street are the automobile and aeronautical industries.

6.3.4. Take-over and mergers between hitherto rival businesses thus became a major preoccupation among the top management of the switching industry. Indeed, the success or failure of their company's systems depended more on considerations of high finance which encouraged commercial integration than it did on the quality of their switching system's technological merits or even

the further boosting of all-out marketing campaigns [11].

In the late 1970s and early 1980s, leaders of the switching industry concentrated on their search for industrial partners sharing the same concerns. In France, this was achieved by taking matters so far as to seek out high-ranking diplomats: one of the Quai d'Orsay's bestknown ambassadors was called in to chair the CGE/CIT-Alcatel industrial group which the Socialist Government, voted in after 1981 elections, had just nationalized.

6.3.5. The above period has consequently been marked by a whole series of meetings between high-level industrial leaders and by secret or confidential get-togethers among financiers in an endless ballet of hesitation waltzes. Naturally, all this took place under the protective umbrella of a State Administration or even higher level governement authorities, the ones with the power to open up national markets.

Until 1984 there were many flirtations but only exceptionally did these lead to marriage.

An example of such fruitless attempts to get together may be seen in the one which took place between Plessey of the United Kingdom and CIT-Alcatel of France in 1982–1983. Their eventual failure aroused some frustration which became even more acute in France when, in order to accelerate the modernization of its network, the British Governement decided in 1984 to throw open to foreign competition a call for tenders for a second digital switching system and no manufacturer of the European Community countries, much less a French one, was even included in the three candidates short-listed.

7. The era of mergers and alliances (1984–199x)

Since 1984 – the beginning of the "era of alliances" –, words have been followed by decisions and "restructuring" has been the name of the game in the switching industry.

7.1. 1984: The AT&T divestiture and its worldwide impact

7.1.1. Pursuant to decisions taken in 1982, AT&T was dismantled on 1 January 1984, and the same date 1984 marked a turning point for the switching industry [12].

AT&T's new-found elbow room for activities outside the United States, combined with its determination to step up its manufacturing activities abroad, were to act as a detonator and, through a series of explosions, bring about a whole series of events which would substantially alter the landscape of the switching industry at the world level.

7.1.2. The giant corporation's first move into Europe took it to the Netherlands on the precise date on which its own new structures came officially into being. For it was on 1 January 1984 that its agreement with the Philips Group took effect [13]. It set up ATT-Philips-Telecommunication, now known as "APT", at Hilversum in the Netherlands, as an international joint venture 50%–50% [14] to manufacture and market switching and transmission equipment. In fact its essential purpose was to develop and manufacture ESS No. 5 exchanges adapted to the specific characteristics of national networks of "European type".

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[11] A glance at the advertising pages of international telecommunication reviews, especially the ITU Telecommunication Journal, is highly revealing in this respect. Equally or even more revealing, the sumptuousness of the pavilions in which telecommunication equipment manufacturers exhibit their products at international fairs such as TELECOM, which since 1971 has been held in Geneva every four years under ITU auspices.. Incidentally, this system has now caught on and exhibitions of the same sort are also being held every four years, with comparable success and at considerable expense to manufacturers, in each of the continents of the world.

[12] Technologically, it is interesting to note that 1984 was also the year in which, in the United States, there was a shift in installing more digital central offices than analog. The statistics for exchange lines installed tipped in favour of digital systems in 1984 with the deployment, essentially, of Western Electric's ESS 5 and Northern Electric's DMS, which in this year had begun to be widely spread [9].

[13] The decision to go ahead with this agreement had been taken in July 1982, i.e. little more than a year after the signing in January 1981 of the agreement between AT&T and the US Department of Justice.

[14] In 1988, AT&T increased largely its participation in APT.

To Philips Telecommunicatie Industrie B.V., adopting the ESS No. 5 system meant abandoning its own PRX-D, a new-generation digital system which seemed to offer great promise and on which much energy had been lavished in the development stage. Unfortunately, as with many other systems such as the Swiss IFS and others (e.g. Vidar in the United States) (see Chapter VIII-11), further development of the PRX-D was proving too costly given the limited markets available, particularly since hopes of its being selected for the DBP's German network had started to fade.

To AT & T, the creation of APT was simply a stage, certainly an important one but nothing more than that, in a long-term strategy for expanding its equipment manufacturing activities outside the United States.

The top management of AT & T had been firmly convinced for over ten years that, telecommunications having become of world-wide potential, it was necessary to break into markets overseas. Since 1980 AT & T had formed a wholly-owned subsidiary, AT & T International Inc., to consolidate the Bell System activities in the international marketplace. Until the anti-trust settlement, however, the subsidiary's activities were concentrated on consulting. Sales, mainly in the Middle East and Asia [15] played only a minor role because Western Electric equipment was not compatible with most foreign communications systems.

The restriction that Western Electric had to make only products designed for use by Bell System companies was removed by the anti-trust settlement of 1984. Thus AT & T's was now left hands free to adapt its product line not only domestically but also internationally.

[15] In 1982, Egypt placed a contract with AT&T International Inc. for eight exchanges of the ESS 1A American type. It was the same type of exchange which was manufactured in South Korea from the end of 1980 by the telecommunication branch of the Lucky Goldstar group, under a joint venture with AT&T International Inc..

7.1.3. Among the somewhat limited circles of the switching world, the creation of APT in Hilversum will remain the best remembered event marking AT & T/Western Electric's irruption on the international scene and into the arena where manufacturers engage one another in competitive strife.

Yet that event was but one of many manifestations of AT & T's active presence outside the United States. Since 1984 many other agreements have been concluded between AT & T and foreign partners. All have taken the form of either joint ventures or share-holdings and have occurred in Europe or Asia, although most of them have not been related to the manufacture of public exchanges. Besides the aims of technical cooperation and the marketing of products of the specific branches (computers, PBXs, VAN networks, etc.) for which the agreements were signed, some of them had the advantage of placing AT & T in an extremely useful strategic position in the country concerned when prospects would eventually open to introduce its equipment, including switching equipment, in the country's public network(s).

The agreement signed in 1985 with the Italian firm of Olivetti, one of Europe's leading office-automation equipment manufacturers, provides just such an example of a beginning of AT & T's strong presence in Italy. In 1988 talks began to take place between AT & T and, on the Italian side, STET and Italtel (Italtel, Italy's leading manufacturer of switching equipment, is a State-controlled company, a subsidiary of the Iri-STET Group). In June 1989, ATT entered Italtel with a participation of 20% in its capital.

7.1.4. The well defended bastions of national networks and switching equipment in the European countries and Japan, nonetheless, had been until the 1989 Italian agreement nearly impregnable to AT & T's attempts to acquire a slice of their market. This had been the case in:

- Ireland, in spite of its one-time ownership of Telectron, a small Irish telecommunication manufacturer, which AT & T bought in 1981;
- the United Kingdom where, as a runner-up, AT & T was one of the short-listed non-British manufacturers contending to provide digital exchanges to speed up the modernization of British Telecom's (BT) network, but failed to obtain the contract. However, the opening of a "800" service by BT did enable AT & T to install ESS No. 5-type exchanges at some nodes of the BT network to provide this service;
- France, where bitter and difficult negociations were conducted at the higher political level in 1986 and 1987 over the transfer of ownership of CGCT. This company, nationalized in 1982 by a socialist government, was sold off in 1987 by the centre-right government with an assured 16% market share of the French Administration's orders for exchanges. At the issue of a hard contest between American AT & T and German Siemens, offering respectively their ESS No. 5 and EWSD systems, the French government came to a Solomon decision of selecting a third contender, LM Ericsson in joint-venture with the French company Matra, with a re-introduction [16] of AXE exchanges (this time, in digital version) in the France Telecom network.

7.2. Other North-American manufacturers extend or restructure their non-American activities

Like AT & T, both of the other leading North American manufacturers were equally concerned to extend, consolidate or restructure their activities abroad. Only some examples, here:

- GTE restructured its industrial interests both in Belgium and Italy where in 1982 it formed an alliance with Italtel, Italy's leading manufacturer of switching equipment. Yet in 1985 an agreement between GTE and Siemens gave the latter control over GTE's switching activities and participations in Europe (Belgium and Italy) and in Asia (Taiwan) in exchange for cooperation between the two companies on the North American market.
- Northern Electric, in the late 1960s, had secured the agreement of the Turkish government to license in a joint-venture the Turkish NETAS firm for producing switching equipment, and over the years NETAS had become the main supplier to Turkish Administration. In Austria, under an agreement with Austrian manufacturer Kapsch and Schrack, Northern won success for its DMS series of exchanges. In the United Kingdom, DMS exchanges were among those being ordered by Mercury, the new British public operator. Northern Electric also gained other footholds in Europe, e. g. in Finland (cooperation with Nokia), and in France (albeit for producing equipment other than for public switching).

7.3. The United States market as a target for non-domestic firms

7.3.1. However, the flow of industrial transmigrations from the country of origin was not a one-way affair, from the North American continent, but was equally strong in the opposite direction, i.e. from Japan and Europe to the United States.

Ever since the deregulation process which had already begun to gather pace in 1976 as a result of FCC decisions, the United States telecommunication market had been steadily opening up. Japanese and European manufacturers had lost no time in following the example of Canada's Northern Electric and building factories there, taking shares in partner companies and even engaging in take-overs when the opportunity presented itself.

7.3.2. Thus in 1982 the British Plessey group bought out the Stromberg-Carlson company, one of the country's longest-established manufacturers of telephone exchanges [17]. After becoming

[16] The AXE system (analog version) had already been manufactured in France for the French Administration by the French company Thomson-Téléphone during a 1978–1983 period.

[17] For Stromberg-Carlson's background, see Volume I, pages 111 (origins) and 481 (reference to its various achievements over almost a century's existence).

a member of the General Dynamics group, Stromberg-Carlson had left its native Chicago and settled in Florida to start manufacturing in 1978 low-capacity "class 5" digital exchanges, mainly for use by the "Independents". Under the trade mark "Century DCO", these exchanges had been among the first models of the new technological generation to see the light of day in the United States where they were highly regarded even though, in the long run, the markets opened up to them remained fairly limited.

7.3.3. The impact of AT & T's divestiture, which became a reality in January 1984, merely amplified the trend described above. Orders from the seven Regional Bell Operating Companies (RBOCs), replacing the former 22 Bell Operating Companies (BOCs), which accounted for 80% of the United States market for public exchanges, ceased to be a captive market for Western Electric (now, AT & T Technologies). Although the old habit of buying from Western Electric and the trusting client relationship that had existed for decades could not simply be broken overnight, the doors of the seven new RBOCs spun off from AT & T became more open to suppliers other than Western Electric.

A U.S. Government 1988 publication ("NTIA Telecom 2000" [10]) gives the following examples of active penetration in the U.S. market of foreign-based communications companies, with quotation of their 1986 sales' figures for telecommunications equipment:

- "NEC, with a U.S. sales and manufacturing subsidiary, recorded sales of $4.2 billion in communications products;
- Siemens, with some 24,000 U.S. employees and U.S. sales in 1987 of $2.6 billion, had sales of telecommunication equipment totaling $533 million;
- LM Ericsson, with a US headquarter in Richardson, Texas, and separate divisions in Kansas, Connecticut, and New Hampshire, had U.S. sales of telecommunication equipment totaling $300 million."

In order to obtain orders, foreign manufacturers were – and still are – obliged to adapt to American requirements and standards their locally-designed systems, which in their own country met requirements that were not very much less stringent, but for the most part substantially different. This is an extremely difficult exercise, the extent of which is and was often underestimated except perhaps when the cost of adapting hardware, and even more, software had to be reckoned [18].

One of the most cruel experiences fell to the ITT group when it had to abandon the American adaptation of its own brilliant 1240 switching system.

7.4. On the North American market, ITT abandons its switching activities. As a result, a takeover by CGE / Alcatel of other ITT worlwide activities in that field

7.4.1. While ITT is a company under American law with its headquarters in New York [19], its activities as a telecommunications equipment manufacturer were in principle conducted entirely outside the United States following the 1925 agreement with AT & T which had made over all its numerous foreign subsidiaries to ITT. Since the ITT 1240 switching system was intended for use in European-type networks, it had logically been developed and streamlined entirely in Europe [20].

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[18] A Northern Business Information Inc. [9] (1986 edition) estimate is that it can cost foreign manufacturers from $250 million to $1 billion to enter the RBOC market, part of which is attributable to the high develoment costs of redesigning switches to meet Bellcore's *Local Access and Transport Area Switching Systems Generic Requirements (LSSGR)* for switches.

[19] For background material on ITT, particularly its conquest of the different industrial firms in the group, see Volume I, pp. 262–263 which include the following notes:

"For telecommunication engineers, particularly switching engineers, ITT's research and achievements were regarded:

- as those of an American company when viewed through European eyes;
- and as the fruit of typically European techniques when viewed through American eyes."

"The double-sided face of Janus, so to speak, if a mythological analogy was sought..."

[20] even thought the novel ideas on which the design of its architecture and principles may have been based, were specifically American in origin (see, above, Chapter IX-7, section 1).

In February 1986, ITT Chairman Rand V. Arskog took the painful decision to withdraw the 1240 system from the United States market [11]. Problems in developing the complex software for the system's distributed architecture and adapting it to the constraints of an American environment had made the system unavailable to the American market for so long that orders were not forthcoming. Over two years' development work aimed at the United States market and costing some US $150 million [12] had proved insufficient and the ITT Chairman found himself obliged to put a halt to the financial haemorrage.

His decision made headlines not only in the financial press and was the subject of leading articles in the major international telecommunication journals, even though the latter had to show some restraint in view of ITT's influence and the readership for which it accounted. The following paragraph from one such leading article adequately expresses the situation which the switching industry was facing [12]:

> "The announcement by ITT that it is abandoning its attempts to modify its system 12 for use in the massive North American market is the first visible sign of the shake-out in the public switching market that the pundits have been predicting for some time. Amidst the welter of cooperative deals that have been the hallmark of the industry in recent months, the ITT decision marks the uncomfortable transition from speculation into fact."

7.4.2. The views expressed in that editorial were quickly confirmed.

The difficulties encountered by ITT with its 1240 system led it to take an even more radical decision in June 1986 when it made over some 70% of its vast array of telecommunication interests and industries to France's Compagnie Générale d'Electricité (CGE) [21]. As everyone in the profession well knew, these ITT interests and industries amounted to a veritable empire operating in almost 100 countries, with those engaged in switching equipment manufacture accounting for some 10% of the world market. Of the jewels in the ITT crown now clustered in the new group controlled by CGE and registered in Amsterdam as Alcatel NV, there were no less than ten higly reputable firms engaged in the construction of switching equipment [22]. Foremost among these were:

- Standard Elektrik Lorenz AG (SEL), in Germany (Fed. Rep.),
- Bell Telephone Manufacturing Co. (BTM), in Belgium,
- FACE, in Italy,
- Standard Eléctrica SA (SESA), in Spain,
- Standard Telephon und Radio AG (STR), in Switzerland,
- Standard Telefon og Kabelfabrik A/S (STK), in Norway,

all of which had a major (if not, for some of them, a large majority) share of their home Administration's market. Moreover, many of them were also suplying equipment on the export market. Altogether, the production of these European companies – and including ITT companies in Austria, Denmark, Finland and Sweden – accounted for almost 40% of Europe's switching market.

The agreement between CGE and ITT took effect on 30 December 1986. "The deal was creating the world's second largest supplier in telecommunications behind AT&T, with annual sales of some US $10 billion and assets worth over $7 billion" [14].

[21] CGE is one of France's leading industrial companies. Its acivities extend over such diverse fields as nuclear power plant, railroad stock, shipbuilding, etc., and, through its CIT-Alcatel subsidiary, it has since 1970 held a predominant position in the French telecommunication industry. Indeed, this was confirmed in 1983 with the merger of the loss-making public telephone activities of the large French Thomson group with the profitable business of CIT-Alcatel (see Chapters VIII-4 and VIII-5).

[22] One notable exception to the ITT/CGE deal was the ITT participation in Standard Telephone and Cables (STC) of the United Kingdom, at a time one of the leading lights in the switching industry. After having sold off most of its overwhelming majority holdings to British investors in 1982, ITT then retained only a 24% stake in STC's capital and STC was no longer an ITT subsidiary [14]. In 1989, with Northern Telecom as its first shareholder, STC is engaged in telecommunications for one third only of its activities, and no more in the public exchange market.

8. Significant new events in the switching equipment industry, 1988–1989

8.1. In a closing speech at the 1987 Phoenix ISS, F.C. Kuznik observed that a trend towards concentration among the main players in the switching equipment industry had been manifest since the 1984 Florence ISS; he forecast that the trend was likely to persist, even asking the question: "Will the number of these main partners reduced to only six or five?".

Writing history is not a journalistic exercise. However, to bring this Chapter, initially written in 1988, up-to-date at its publication in 1990, let us add a brief account of some new and significant events which have occurred in the interim to confirm Kuznik's wiews. For, indeed, some of the market situations in our worldwide description of the switching equipment industry have been further reshaped.

8.2. Most of these events have affected the European area

They are partly due to the policy thrust from the Commission of the European Communities in Brussels. This policy, defined not without some reticence on the part of many national PTT administrations, had been submitted in the form of a "Programme for action" for the 12 countries of the European Community ("EC") and, on 30 June 1987, gave rise to the publication of the EC "Green Paper on Telecommunications" [15].

Acknowledging the differences in currently existing situations in the 12 EC countries and advocating regulatory changes in their telecommunication structures, the Green Paper set out a broad series of "Proposed Positions" for "Open Network Provision" in Europe. One of these proposals relates more specifically to the subject of this Chapter: namely, the opening to non-national manufacturers of the national procurement markets of the telecommunication Administrations of the EC countries. Such an opening will, of course, affect first and foremost the switching equipment of the European Administrations' networks.

This objective must be regarded as a long-term one. The Commission will (indeed it has already started) call for fair, open and not exclusively national tendering by imposing monetary values thresholds above which tenders must compulsorily be open to foreign competitors.

Another shorter-term line of action of the Green Paper concerns the rapid and full opening of the terminal equipment market to competition, a Community arrangement which is to be completed at the end of 1990.

Open Network Provision assumes the existence of well and precisely defined standards for both telecommunication networks and the terminal equipment which may be connected to them, i.e. the interfaces to the network. It is to this end that the European Telecommunications Standards Institute ("ETSI") has been created. It opened its doors and became operational late in 1988 in Sophia-Antipolis on the French Riviera, near Nice, under the direction of D. Gagliardi. The EC countries have agreed that all national standards that conflict with the ETSI standards, known as "ETS" (European Telecommunications Standards), will have to be withdrawn. This will guarantee homogeneity of the telecommunication networks of the EC countries.

8.3. Naturally, those in charge of switching equipment companies have not been idle pending implementation of the long-term lines of action defined in the Green Paper, with the bright prospect it offers for promoting a major expansion of the European telecommunication market. In the years 1988–1990, many industrialists have taken the initiative either to merge with other switching equipment manufacturers or at least to secure a large minority holding in them.

We have already cited the re-entry into France of LM Ericsson with its AXE digital system in 1987 (section 6 and Box A of Chapter VIII-9), following its entry into the British and Swiss markets in the early 1980s (section 7 of the same Chapter). Besides these events, the most significant ones relating to the expansion of some switching manufacturers into European national markets have occurred in the United Kingdom and Italy. Let us therefore concentrate exclusively on those two countries.

8.4. The United Kingdom switching industry had been experiencing a series of company mergers and desertions from the 1970s onwards:

- in 1972, the Automatic Telephone & Electric Ltd. of Liverpool – the famous father-house of the 1912 British Strowger system – was taken-over by Plessey;
- in 1982, following a partial sale to British interests of ITT stock in Standard Telephone & Cables (STC), STC a few years later abandoned its development and manufacture of switching equipment for public exchanges;
- in December 1985, after an unsuccessful attempt by the British GEC to take over Plessey, the two companies agreed to form a joint-venture called "GEC Plessey Telecommunications" – better known as GPT – to develop, manufacture and market their telecommunication equipment, especially the "X" switching system that they had developed jointly (see Chapter IX-5) but manufactured separately; this new venture included Stromberg-Carlson, Plessey's subsidiary in the United States;
- in September 1988, GEC and Siemens of Germany jointly paid 3.1 billion US dollars for Plessey, including its 50% share in GPT. The actual purchase went ahead only after a long rear-guard battle by the Plessey management and the clearing of many administrative obstacles raised by both British governmental authorities and the European Community Commission in Brussels, which finally decided that the bid did not violate European rules on competition. Thus, after two long periods of absence from the British market, dating from the First and Second World Wars, respectively [23], Siemens – through its now 40% share in GPT – made its comeback into the club of British switching equipment manufacturers.

8.5. As described in section 5 of Chapter IX-9, in mid 1989 AT & T made a major entry into the European telephone equipment market by forming an alliance with both Italtel, the foremost Italian producer of switching equipment, and STET, its holding company which also controls the SIP, the company which operates all of Italy's local and regional networks. There were big headlines in the European financial papers: "Italy opens the doors of the European market to the American AT & T".

In fact, the entry was more modest: under the terms of the agreement concluded, AT & T acquired only 20% of Italtel, and STET an identical share of AT & T Network Systems International. AT & T's policy of extending its activities in Europe is, however, a determined one, as it manifested again in January 1989 by securing a further 10% holding in APT, its joint-venture with Philips of the Netherlands.

8.6. However important those events, what will certainly make 1990 an even bigger watershed for the switching equipment industry is the opening of new market prospects offered by the abrupt and radical changes which occurred on the political scene with the abolition of the "Iron curtain" between the countries of Western and Eastern Europe.

For many years now, market analysts have forecast that the areas where the largest expansion of telephone lines will take place would be the USSR and other East European countries. All those countries have ambitious plans to deploy new telephone exchanges to satisfy the public demand. The exchanges themselves had to be of modern types using digital switching technology. Until now, however, such expansion has been hampered by the lack of capital investment and appropriate technology, especially for the most modern electronic components needed in digital technology. Exports of telephone switch-

[23] At the beginning of the century, "Siemens Bros." of London, initially founded in the 1870s by (Sir) William Siemens to manufacture submarine telegraph cables, had been highly active in telephony, especially in promoting applications of the Siemens patents for automatic exchanges. After the confiscation of Siemens Bros. as enemy goods during World War I, the company was revived in the 1920s and 1930s as the British "Siemens Brothers Ltd." and continued its activities in automatic switching before disappearing again during World War II. (see Volume I, pp. 212, 226 and 236)

ing equipment to East European countries has been blocked by the Cocom rules imposed on Western countries (even if these rules have not applied to their exports to the People's Republic of China). Those restrictions are now to be eased and the switching equipment manufacturers of the Western world are already engaged in intense marketing activity within the East European countries, especially in an attempt to renew the industrial relations which broke down in 1945–1947.

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CREDITS

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A GLOSSARY

A Glossary of some of the terms used throughout this book, concerning switching, signaling, software and traffic theory, and which may raise difficulties for laypersons reading the book

Most of the definitions given hereafter are official ones in international reference books on "Telecommunication Vocabulary", especially those edited by the Internationl Telecommunication Union (ITU). They have sometimes the disadvantage of being very formal. If further explanation of a term is required, see for instance [1].

Address information (in signaling). The totality of digits at a point in the network which locate the called party, or those digits which are necessary for forward routing.

Analog switching. Switching of continuously level varying information signals.

Assembly language. A low level language whose instructions are usually in one-to-one correspondence with computer instructions and that may provide facilities such as the use of macro-instructions.

Backward signal. A signal, used for the establishment or control of a connection, sent in the opposite direction as call set-up.

Bit. a contraction of the term *binary digit*. A bit is one digit of a binary set. The binary set is usually represented by the digits 0 and 1.

BHCA = Busy Hour Call Attempts. In the switching language, a unit to express the traffic capacity of an exchange when it is confronted by the heaviest traffic of high-traffic days.

Byte. A byte is a group of bits. Generally a byte refers to a group of eight bits, a group whose official international name is "octet".

Call processing. The execution of all the functions required to set up, hold, supervise and release connections.

Channel-associated signaling. A signaling method in which the signals for the traffic carried by a single channel are transmitted in the channel itself or in a signaling channel permanently associated with it.

Charging. Assigning a fee to the use of a circuit or facility.

Circuit switching. The switching of circuits for the exclusive use of the connection for the duration of a call.

Codec: Coder / decoder. A device for converting analog modulation signals into digital modulation and conversely.

Common channel signaling (CCS). A signaling method in which a single channel conveys by the means of *labeled* messages, signaling information relating to a multiplicity of circuits or calls and other information such as that used for network management.

Concentration (in a switching stage). A configuration wherein the number of inlets carrying traffic into the switching stage is larger than the number of outlets.

Concentrator (line concentrator). A switching equipment located away in a local line network and enabling the traffic between the local exchange and a number of subscribers to be carried by a smaller number of lines.

Crossbar switch. A switch with a matrix of mechanical crosspoints having electromechanically operated activation means common to crosspoints in the rows and columns.

Crosspoint. A set of physical contacts that operate together to extend the path of a connection through a particular stage of a space-division switching network.

Digital switching. Switching of discrete-level information signals.

Directory number. The subscriber number listed in the directory against the name of the subscriber.

Distributed control. A control in which groups of functional units each serve parts of control functions.

Equipment number. An identifier which defines the input port of a telephone exchange to which a subscriber's line is connected and the corresponding line equipment.

Erlang. The unit of traffic intensity.

Exchange = central office (North American). An aggregate of traffic-carrying devices, switching stages, signaling means and controlling means enabling incoming lines to be connected to outgoing lines as required by individual callers.

Expansion (in a switching stage). A configuration wherein the number of inlets carrying traffic into the switching stage is smaller than the number of outlets.

Flag (in signaling). The unique pattern on the signaling data link used to delimit a signal unit.

Forward signal. A signal, used for the establishment or control of a connection, sent in the same direction as call set-up.

Four-wire switching. Switching using a separate path for each direction of transmission.

Frame (in a multiplex structure). A set of consecutive digital time slots in which the position of each digital time slot can be identified by reference to a frame alignment signal.

Frame alignment. The state in which the frame of the receiving equipment is correctly phased with respect to that of the received signal.

High-level language (HLL). A programming language that does not reflect the structure of any given computer or any given class of computers.

In-band signaling. A signaling method in which signals are sent over the same transmission channel or circuit as the user's communication and in the same frequency band as that provided for the user.

Integrated digital network (IDN). A network in which connections established by digital switching are used for the transmission of digital signals.

Integrated services digital network (ISDN). An integrated digital network in which the same digital switches and digital paths are used to establish connections for different services, for example, telephony, data, facsimile.

Internal blocking. The condition in which a connection cannot be made between a given inlet and any suitable free outlet owing to the impossibility of establishing a path within the switching element being considered.

Label (in common channel signaling). Information within a signaling message used to identify typically the particular circuit, call or management transaction to which the message is related.

Marker. That part of the common-control equipment of a switching system which, from information identifying two points to be connected, tests for an idle path through the various stages of the switching network of an exchange and operates the appropriate crosspoints to establish the connection.

Message transfer part (in common channel signaling). The functional part of signaling messages, which transfers them as required by all the users and which performs the necessary subsidiary functions, for example, error control and signaling security.

Multifrequency signaling (MF signaling). A voice-frequency signaling method in which the signaling information is represented by compound signals, each consisting of two frequencies from a set of m frequencies.

Octet. The official international name of a group of eight bits. In North-America, the term "octet" is relatively unfamiliar and the term "byte" is used instead.

Operating system. Software that controls the management and the execution of programs.

Out-band signaling. A signaling method in which signals are sent over the same transmission channel or circuit as the user's communication but in a different frequency band from that provided for the user.

PBX (Private Branch Exchange). A switching system owned or leased by an organization

and generally installed on its premises, which provides lines for internal communications between local extensions and a smaller number of lines to the public network.

Port. A point at which traffic enters or leaves a switched network – or a terminal of the switching network of an exchange.

Pulse Amplitude Modulation (PAM). If an analog waveform is sampled, the signal magnitude of the sample instants can be recorded by pulses of that magnitude at the same relative instants of time. The resulting pulse stream is a PAM signal.

Pulse Code Modulation (PCM). If an analog waveform is sampled so as to produce a PAM signal, the magnitude of each pulse in the PAM signal can be represented by a binary word. The process is called Pulse Code Modulation and the resulting string of binary words is a PCM signal. The process includes the function of regenerating an analog waveform from a PCM signal.

Reed relay. A switching matrix component, or crosspoint, composed of one or several metallic contacts and one or several control coils. Each contact is made of two flexible magnetic rods sealed in a glass envelope. Contact closure can be held by electric (with an additional contact) or magnetic (with a permanent magnet) latching.

Register. That part of the common-control equipment of a switching system which receives and stores address information for the subsequent establishment of the desired connections. Registers are released once the call is established.

Scanning (in switching). A process of sequential interrogation, initiated periodically, that determines the status of each device within a group of commonly controlled devices.

Seizing signal. A forward signal sent at the start of a call.

Signal unit (in common channel signaling). A group of bits forming a separately transferable entity used to convey information on a signaling link.

Signaling system. The repertoire of signals and the procedures for their interpretation and use, together with the hardware and/or software needed for the generation, transmission, and reception of the signals.

Software. Computer programs, procedures, rules and any associated documentation concerned with the operation of a system.

Space-division. The separation in the space domain of a plurality of transmission channels between two points.

Space-division switching. The switching of inlets to outlets using space-division techniques.

Subscriber (in telephony). A person or body to which services provided by a telephone network are made available by means of a telephone station or a private telephone installation permanently assigned by the network operating agency.

Switching. The establishment, on demand, of an individual connection from a desired inlet to a desired outlet within a set of inlets and outlets (for as long as is required for the transfer of information).

Switching matrix. An array of crosspoints in a matrix which, from a traffic point of view, operates as a switch.

Switching network. The switching stages of an exchange taken collectively.

Switching stage. An aggregate of switches constituting a subset of the switching center and designed to operate as a single unit from a traffic-handling point of view.

Synchronization. The process of adjusting the corresponding significant instants of signals to make them synchronous.

Tandem. Mode of operation in which the traffic coming from exchanges is switched to other exchanges.

Time-division. The separation in the time domain of a plurality of transmission channels between two points.

Time-division switching. The switching of inlets to outlets using time-division (multiplexing) techniques.

Time slot. Any cyclic time interval that can be recognized and defined uniquely.

— (in switching). A unit interval in the time domain, capable of providing a channel.

Translation (in automatic switching). Conversion

of address signals associated with a call into other information or signals, in a form suitable for controlling subsequent selection and routing functions.

Reference

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Indexes

I. SCIENCE AND TELECOMMUNICATION PERSONALITIES

II. TELECOMMUNICATION COMPANIES AND INSTITUTIONS QUOTED: NAMES AND ACRONYMS

III. MAIN SWITCHING SYSTEMS QUOTED IN THE BOOK

In this list, the code-names given are those of systems for public telephone exchanges. Codes for systems that have been used only for field trials are not included.

IV. SUBJECT INDEX

In this Index, the symbol " * " represents the key-word, subject of the reference.